Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia

Part 3 - Risk Assessment for Threats to Ecosystems, Species and Communities: A Review

Natural Heritage Trust
Helping Communities
Helping Australia
An Australian Government Initiative

Murdoch University
Perth, Western Australia

Murdoch LINK

CPSM
Centre for Phytophthora Science and Management

Department of the Environment and Heritage

This publication is available online at:
http://www.deh.gov.au/about/publications/index.html

For additional hard copies, please contact the Department of the Environment and Heritage, Community
Information Unit at ciu@deh.gov.au or 1800 803 772.

ACKNOWLEDGEMENTS

The Centre for *Phytophthora* Science and Management would like to thank the Project Reference Group (membership below) for their guidance and extensive input into this document.

Name	Agency	State
Hugh Bramwells	Department of Sustainability & Environment	Victoria
David Cahill	Deakin University	Victoria
Paul Gadek & Stuart Worboys	James Cook University	Queensland
Keith McDougall	Department of Environment & Conservation	NSW & liaison with the ACT
Ian Smith	Department of Sustainability & Environment	Victoria
Tim Rudman	Department of Primary Industries, Water & Environment	Tasmania
Kevin Vear	Department of Conservation & Land Management	WA
Renate Velzeboer	Department of Environment & Heritage	SA

The Australian Government Department of the Environment and Heritage provided funding for this project, and the Centre for *Phytophthora* Science and Management would like to thank Ms. Belinda Parkes from the Department for her support throughout the project.

The authors would like to thank Mrs Janet Box for excellent administrative support.

How to cite this document:

B Wilson, K Howard, E O'Gara and GEStJ Hardy (2005) Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 3 - Risk Assessment for Threats to Ecosystems, Species and Communities: A Review. A report funded by the Commonwealth Government Department of the Environment and Heritage by the Centre for *Phytophthora* Science and Management, Murdoch University, Western Australia.

ABBREVIATIONS

CALM	The Department of Conservation and Land Management, Western Australia
CPSM	Murdoch University, Centre for Phytophthora Science and Management
DPIWE	Tasmanian Department Primary Industries, Water and Environment
DWG	Dieback Working Group
EPBC	Environment Protection and Biodiversity Conservation Act, 1999
FIS	Flora Information System
FMEA	Failure Modes and Effects analysis
GENHAZ	Genetic hazard
GIS	Geographic Information Systems
GMO	Genetically modified organism
GPS	Global Positioning System
HAZOP	Hazard and Operability Analysis
NATA	National Association of Testing Authorities, Australia
NIASA	Nursery Industry Accreditation Scheme (Australia)
NTAP	The National Threat Abatement Plan
P	Proximity to *Phytophthora* infestation for scoring of threatened plant species
PMA	Phytophthora Management Areas
PVA	Population Viability Assessment
RPN	Risk Priority Number
S	Species Status for scoring of threatened plant species
SCRIPT	South Coast Regional Initiative Planning Team
SOD	Sudden Oak Death
TSSC	Threatened Species Scientific Committee
VPC	Vertebrate Pest Committee

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii

ABBREVIATIONS iv

1 INTRODUCTION 1

1.1 *Phytophthora cinnamomi* dieback: a Key Threatening Process to Biodiversity 1

1.2 Risk analysis, assessment and management 2

1.3 Australian Standards: risk analysis, assessment and management 5

1.4 Analysing risk 5

1.5 Managing risk 6

2 PROJECT OBJECTIVES 7

3 PROJECT METHODOLOGY 8

4 REVIEW OF RISK ASSESSMENT PROCESSES AND MODELS 9

4.1 Risk concepts and perceptions 9

4.2 Risk assessment and analysis methods 9

4.2.1 Identification of hazards, components and pathways 11

4.2.2 Risk assessment and uncertainty 12

4.2.3 Risk ranking and scoring systems 12

4.2.4 Expert opinion in risk ranking and assessments 14

4.3 Risk assessment in various fields 14

4.4 Risk assessment in natural resource management (ecological risk assessment 15

4.4.1 Risk assessment for biological invasions 16

4.4.2 Assessment of ecological attributes 17

4.4.3 Disturbances and resilience 18

4.4.4 Goals for environmental risk assessment 18

4.4.5 Risk assessment in Australian natural resource management 18

4.5 Databases for *Phytophthora* dieback available across Australia 19

4.5.1 Positive isolations, mapping and database records of the current known active range of *P. cinnamomi* 19

4.5.2 Laboratory Detection Services 21

4.5.3 Vegetation vulnerability mapping 21

4.5.4 Susceptible plant species (rare and threatened species that are susceptible to P. cinnamomi) 24

4.5.5 Susceptible fauna species (rare and threatened species that are susceptible to *P. cinnamomi*) 25

4.5.6 Listed threatened communities that are susceptible to *P. cinnamomi* 26

4.5.7 Designated long term monitoring sites 26

4.6 Risk mapping and analyses-spatial models 27

4.6.1 Criteria for risk mapping models 32

4.6.2 Summary of the best models and features for risk mapping in Australian native ecosystems 33

4.7 An overview of existing risk assessment models 35

4.7.1 Current processes for risk assessment and setting priorities for *P. cinnamomi* threats 37
4.7.2 Criteria for risk assessment models 40
4.7.3 Summary of the best models and features for risk assessment in Australian native ecosystems 41
5 RECOMMENDATIONS AND CONCLUSIONS 45
5.1 Mapping and spatial models..46
5.2 Risk asssesment and prioritisation for species, communities and localities model.......46
5.3 Procedures followed for developing risk ranking models 47
6 GAPS IN KNOWLEDGE AND FUTURE RESEARCH 48
6.1 Databases and information for *Phytophthora* dieback available across Australia..........48
6.2 Impacts of *P. cinnamomi* on communities and ecosystem function 48
6.3 Risk mapping in Australian native ecosystems 49
6.4 Risk assessment models..50
7 REFERENCES 51
8 GLOSSARY...60

1 INTRODUCTION

1.1 *Phytophthora cinnamomi* dieback: a Key Threatening Process to Biodiversity

Australia has highly diverse and unique flora and fauna communities and is one of the major repositories of biodiversity in the world. It has approximately 7% of known animal and plant species (Prime Minister's Science Council, 1992; State of the Environment Advisory Council, 1996). The level of endemism (>49.4%) is very high in Australia and is a large component of the total endemic species of the world (World Conservation Monitoring Center, 1992; Department of Environment Sport and Training, 1994).

Since European settlement, a wide range of novel disturbance factors has impinged upon the flora and fauna. The number of endangered plant species in Australia is comparable to the highest rate found in the United States of America (Briggs and Leigh, 1996). Key threats to threatened plants, animals and ecological communities have been identified under the Commonwealth's *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999*. Examples include: predation by the cat, predation by the fox, and land clearance. The number of extinctions of Australian mammals is significantly higher than elsewhere in the world (Burbidge and McKenzie, 1989; Morton, 1990; Short and Smith, 1994; Maxwell *et al*., 1996; Smith and Quin, 1996). Twenty seven species of mammals have become extinct and 34 listed as critically endangered or endangered (Environment Australia website, htpp:/www.ea.gov.au, accessed 12/07/05).

Dieback caused by the soilborne plant pathogen *Phytophthora cinnamomi* was listed as a 'Key Threatening Process' in the Australian environment in 2000 (Environment Australia, 2001). The threatening process is the lethal epidemic of 'Phytophthora dieback' that occurs when the presence of the pathogen coincides with conducive environmental conditions and susceptible vegetation. This disease leads to major disruptions of plant communities. The consequences of the threatening process include:

- the extinction of populations of flora species
- reduction in primary productivity within affected ecosystems
- the loss and degradation of flora and fauna habitat.

The National Threat Abatement Plan (NTAP) for *Phytophthora* (Environment Australia, 2001) was developed under the *EPBC Act 1999*. The two major objectives identified were to:

- promote the recovery of threatened species and ecological communities that are known or perceived to be threatened by *P. cinnamomi*
- limit the spread of *P. cinnamomi* into areas where it may pose a risk to threatened species and communities, or into areas where it may lead to further species or communities becoming threatened.

The Act requires the Commonwealth Government to prepare and implement a threat abatement plan, for nationally coordinated action to mitigate the harm caused by *P. cinnamomi* to Australian species, particularly threatened flora, fauna and ecological communities. The 'National Threat Abatement Plan for Dieback Caused by the Root-Rot Fungus *Phytophthora cinnamomi*' (Threat Abatement Plan) was released in 2001 (Environment Australia, 2001).

This project, funded by the Commonwealth Government Department of the Environment and Heritage, is one of the most significant actions to be implemented from the National Threat Abatement Plan to date. The project has two major components:

- to review current practices for the management of *P. cinnamomi* in natural ecosystems of Australia, and identify benchmarks for best practice
- to develop a ***risk assessment*** criteria and a system for ***prioritising management*** of sites that are or could be threatened by *P. cinnamomi*

The project is presented in a four-part document entitled **Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia:**

Part 1 - A Review of Current Management

Part 2 - National Best Practice Guidelines

Part 3 – Risk Assessment for Threats to Ecosystems, Species and Communities: A Review (this document)

Part 4 – Risk Assessment Models for Species, Ecological Communities and Areas.

The need for a national approach was evident in the preparation of the NTAP where various approaches to assess risk have been undertaken across Australia. In some states the approaches to assess risk have been very limited or nonexistent (e.g. Queensland), in other states attempts have been made to assess risk (e.g. South Australia), and in others risk assessment has been extensive (e.g. Western Australia). The diversity of approaches can lead to conflicting information and messages to the public, management agencies, industry and funding agencies with regard to the risk, conservation priorities, and research priorities. This can be an impediment to implementing the NTAP. When resources are limited there is a need to ensure that resources can be utilised most effectively to achieve policy goals. Consequently, there is a need to develop a robust national risk assessment model.

1.2 Risk analysis, assessment and management

All human decisions or actions involve taking some risk. The question is often not whether or not to take a risk, but which risk is the most acceptable? Individuals, organisations, business, governments, industry and academic institutions all face similar problems in risk management. Risks cannot be avoided or eliminated so risk assessment and analyses provide the ability to define what may happen, assess the associated risks and uncertainties and assist in choosing alternative decisions based on these uncertainties. The concepts of risk and uncertainty remain ambiguous and this is exhibited in the variation in methods and approaches undertaken in different applications and disciplines. For example, in engineering, risk is often considered as being applied to physical property, and risk analysis is estimated in a quantitative manner, while in business and project management risk is perceived as a subjective measure of uncertainty (Aven, 2003). Thus, there is a need to clarify the definition of risk and the processes of risk analysis.

Risk can be defined as the probability of occurrence of an event, and over time has attained a negative interpretation: the chance of a hazard or bad consequence. There are major differences in the use of terminology (Beer and Ziolkowski, 1995). In the United States of America, **risk assessment** refers to the component of the overall process that involves the calculations (probabilities, frequencies, magnitude, likelihood and consequences), while **risk analysis** is the overall process (risk assessment, management, perception and communication). In contrast, in Australia **risk analysis** generally refers to the calculations, whereas **risk assessment** is understood as the total process (also see Section 1.3). However, the "Risk Analysis Framework" (Commonwealth of Australia, 2005) developed for genetically modified organisms (GMOs) uses the term risk analysis in the widest sense to include risk assessment, risk management and risk communication. The document notes that the term 'risk analysis" they employ is synonymous with the term 'risk assessment" as used by the AS/NZS 4360 (1999; 2004) and is in line with terms employed by WHO, WTO, FAO and the Codex Alimenatarius Commission.

In the present document definitions from The Australian Standard for Risk Management (AS/NZS 4360: 1999; 2004) (Section 1.3) will be employed except when quoting from or referring to the documents and text where this is not used.

The main features of decision making based on risk assessment include a number of components (Figure 1.1). The problem of making decisions for risk analyses is commonly seen as the starting point and can be formulated as a process for deciding between alternative options. The list of alternatives may be shortened by eliminating those that are not possible, practical, and economically feasible or that conflict with stakeholder values, organisational goals or other criteria. In addition, it is often a management requirement to determine the cost of decisions versus the benefits (cost-benefit). Cost-benefit analyses are, thus, often undertaken and employed to assist in the decision making process (Figure 1.1).

The application of such decision making processes involving risk assessment in natural resource and ecosystem management has not yet been widespread (Morton *et al*., 2002; Possingham *et al*., 2002; Hart *et al*., 2003; Carey *et al*., 2004). However, the identification of biodiversity values, and potential risks and threats to such values, is an essential requirement for good natural resource management.

Natural resource managers are often faced with serious resource limitations so the prioritisation of values and risks or threats is necessary so that the resources available can be employed effectively to achieve goals and policies. The process of prioritisation can also assist in identifying what values, communities and areas should be monitored in an effective manner (Possingham *et al*., 2002; Carey *et al*., 2004).

This report evaluates criteria and models for assessing the risk of infestation by the pathogen *P. cinnamomi* based on a literature review of previous studies and information obtained from current studies, unpublished information and expert opinion. It examines risk assessment models from other areas but concentrates on models for natural resource management. This report also identifies the databases available in Australia necessary for the risk assessment process and the gaps in data that need to be filled. The results of this review and evaluation were employed to develop models suitable for assessing the risks and consequences of infestation of *P. cinnamomi* in Australia (Part 4 – Risk Assessment Models for Species, Ecological Communities and Areas). Spatial models of the risk of infestation to areas are assessed together with and risk assessment methods for prioritisation of species, communities and areas. The models are developed to be applicable at national, state and local levels. The models are, thus, based on current scientific knowledge, and provide structures and support for decision making. The aim is to develop the models as useful tools to assist land managers including government agencies, local government, local management bodies and community groups for making decisions on the risks from *P. cinnamomi* and the priorities for management and recovery actions.

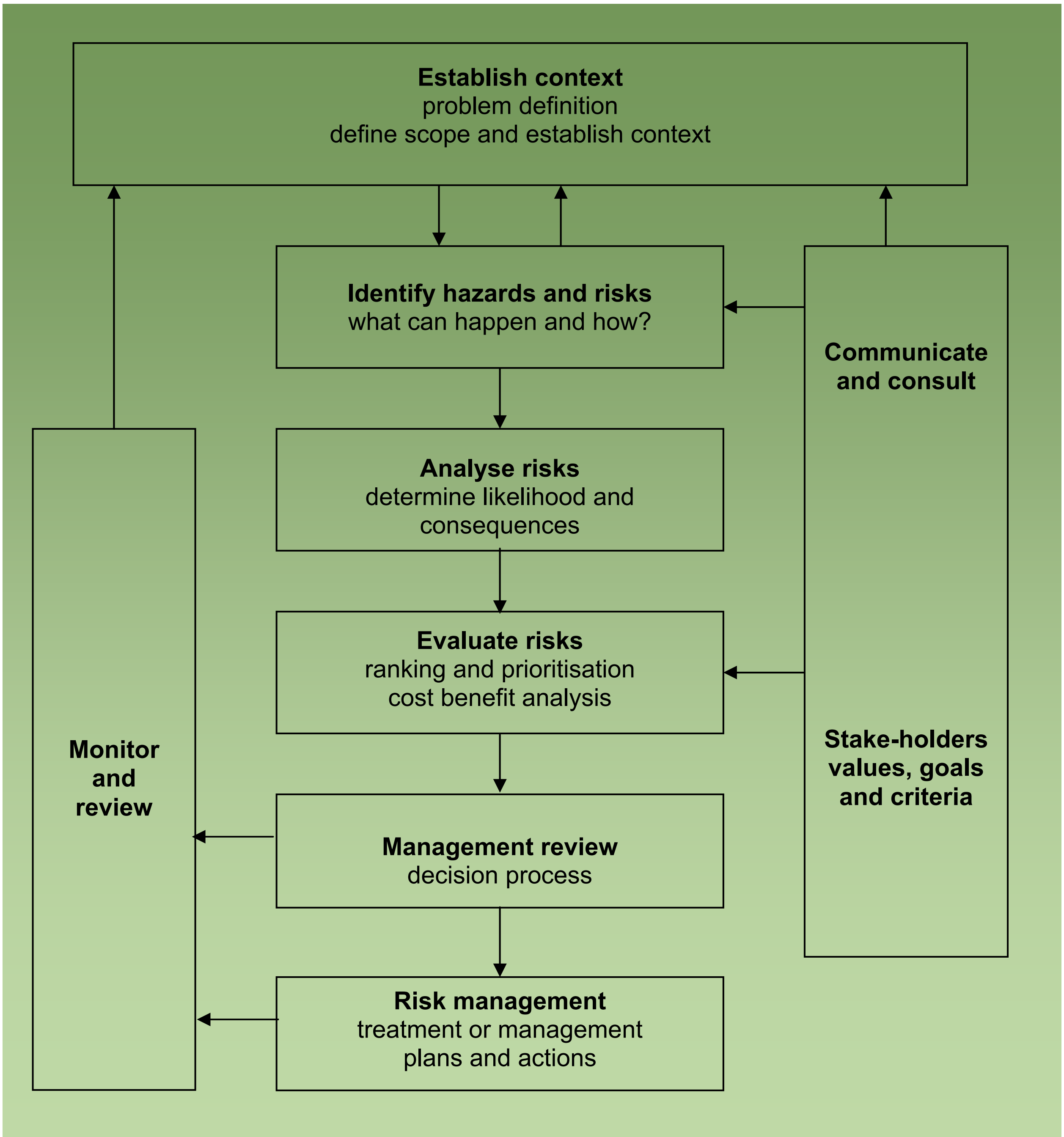

Figure 1.1 The risk management cycle (after AS/NZS 4360: 2004).

1.3 Australian Standards: risk analysis, assessment and management

The Australian Standard for Risk Management (AS/NZS 4360: 2004) is a standard procedure commonly applied to risk assessment in Australia. It is designed to provide a generic template for risk analysis that is applicable for a range of areas. The process (Figure 1.1) involves the following steps:

- *Establish the context*. This step assesses the organisations involved, policies and goals that are important, relationship to the wider community/stakeholders, what changes are feasible and what risks are acceptable. The level of risk assessment and limits on time and money can also be determined.
- *Identify the risks (hazards)*. This step identifies the risks and describes them briefly.
- *Analyse the risks*. Here the *s*ource of risk, the likelihood of occurrence and magnitude of the consequences are identified. Analyses can be quantitative or qualitative (based on best estimates/expert opinions) depending on the information available and cost of undertaking the analyses.
- *Evaluate and prioritise the risks*. Here the relative risks are determined and prioritised for action.
- *Treat risks*. Options are identified and consideration is given as to whether actions should be taken. For example, accept the risk and do nothing, or alternatively reduce the likelihood, or reduce the consequences. Management actions are then employed to mitigate the risk.
- *Monitor and review*. The effectiveness of management or control measures need to be monitored and risks reviewed in light of changing environments or circumstances.
- *Communicate and consult*. Effective communication of risk assessment to the stakeholders is important at all stages of the process to ensure those with responsibilities understand the basis on which decisions are made.

1.4 Analysing risk

Once the context has been established and the hazard identified, a description of the source and pathways through which harm may eventuate is developed. The next step involves determinations of the likelihood of occurrence and magnitude of the consequences. This considers the seriousness (consequence) and the chance or probability (likelihood) that the harm will occur. Analyses can be quantitative or qualitative.

An assessment of consequences may include consideration of factors such as the severity of the risk, the spatial and temporal extent, together with cumulative affects and the reversibility of the risk (OGTR, 2005). Assessment of severity can take into account the number and magnitude of the impacts. It also can assess whether impacts are rapid, if they have long-term effects and whether they are acceptable. The spatial extent to which the impact may extend (local, regional or national) and the temporal extent (day, year or decade) need to be assessed. The frequency of the impact could also be important (intermittent, regular or continuous). The potential impact of the hazard in addition to other conditions could be important, and the length of time to reverse or manage impacts may be important factors for assessing consequences.

Likelihood can be expressed as a measure of both frequency and probability. Factors that need to be considered include the circumstances necessary for the presence of the hazard, and the conditions for there to be an adverse outcome.

A matrix designed as a tool to estimate the risk is often employed to provide a format for considering the relationship between the consequence and likelihood of the hazard (Table 1.1). Here the combination of both likelihood and consequence contribute to determination of adverse outcomes and the necessity for management. The risk estimates include:

- Negligible - the risk is very low and actions are not required at the time
- Low - risk is minimal, but may require some actions in addition to normal practice
- Moderate - risk is of concern and actions need to be taken
- High – the risk is unacceptable and actions must be taken

The asymmetrical nature of risk matrices is because not all risks have the same relationship between likelihood and consequence. The matrix is not prescriptive, but is a tool for decision making.

Table 1.1 Risk assessment matrix (OGTR, 2005).

Likelihood	**Consequences**			
	Marginal	**Minor**	**Intermediate**	**Major**
Highly likely	Low	Moderate	High	High
Likely	Negligible	Low	High	High
Unlikely	Negligible	Low	Moderate	High
Highly unlikely	Negligible	Negligible	Low	Moderate

1.5 Managing risk

Once the risk analysis/assessment has been undertaken consideration is given as to whether actions should be taken to reduce the likelihood or to reduce the consequences. Management actions can be employed to mitigate the risk. The pathways and sources identified in the risk assessment provide the basis for strategic selection of how to undertake treatments or management, where they are best applied and when. Here the focus is likely to be on prevention but management of adverse affects may be the only option in some cases.

2 PROJECT OBJECTIVES

This report will address a number of the objectives of the National Threat Abatement Plan (Environment Australia, 2001). The objectives are:

- assessment of the level of risk of *P. cinnamomi* spreading to and infecting populations and communities
- development of a national methodology/generic framework for determination of risk for threatened species, communities and areas (Part 4: Risk Assessment Models for Species, Ecological Communities and Areas)
- ranking of species, communities and areas for protection (Part 4: Risk Assessment Models for Species, Ecological Communities and Areas).

The report considered the following factors:

- the biogeography of susceptible species, communities and habitats and the disease caused by *P. cinnamomi* to species and/or ecological communities
- the *EPBC Act 1999* list of threatened species and ecological communities as a basis for making decisions
- an estimate of the management costs involved (planning, on ground operations, monitoring) and the potential effectiveness of control measures (Part 4: Risk Assessment Models for Species, Ecological Communities and Areas)
- cost benefit analysis methods in the risk assessment process to help compare the relative merits of different management approaches (Part 4: Risk Assessment Models for Species, Ecological Communities and Areas).

3 PROJECT METHODOLOGY

The methodology used was as follows:

1. A literature search was undertaken and unpublished information and expert opinion obtained from the members of the Project Reference Group (see page ii). The information was reviewed in four areas:

- Current databases and information available for the distribution and mapping of *P. cinnamomi* in Australia were reviewed. The review identified what data were available in the states and territories and assessed the data quality methods of reporting
- Risk assessment models in other fields were reviewed and assessed for their suitability for incorporation into risk models in relation to *P. cinnamomi* in Australia
- The existing risk assessment processes in relation to *P. cinnamomi* were reviewed to identify key similarities and differences in processes being used across Australia and elsewhere
- Criteria to assist in assessing risk models for their applicability for the assessment of *P. cinnamomi* risks in Australia were identified. The models reviewed were assessed for their suitability to address the objectives of the project and applicability for national models.

2. Following the reviews, risk assessment criteria and processes that could be adopted nationally for Australia were developed in two areas:

- Risk mapping models to identify susceptible uninfected areas and the risk and probabilities of infestation were proposed based on empirical and spatial models including Geographic Information Systems (GIS)
- Risk assessment models to determine the risk to threatened species, communities and areas and develop prioritisation of actions based on the assessments.

3. The draft models were initially sent to natural resource managers and staff in different states to assess their applicability and usefulness. They were asked to test the models by using examples from their own region. The models were refined based on the feedback obtained.

4. Significant gaps in knowledge of the pathogen and its effects, and of risk assessment methods were identified and requirements for future research that may address these identified.

4 REVIEW OF RISK ASSESSMENT PROCESSES AND MODELS

4.1 Risk concepts and perceptions

Humans face risks at a number of levels and society now requires higher safety, protection and reliability from all hazards and risks (Ansell and Wharton, 1992; Aven, 2003). Debates regarding risk issues often lack clarity and confuse the difference between facts or judgements, and as to what are the uncertainties (Aven, 2003). **Strategic risk assessment** often refers to the use of risk assessment methods to determine corporate activities such as allocating resources or making informed decisions (Beer and Ziolkowski, 1995). For example, a business or government department may use the approach to forecast problems and disagreements, and as a basis of policy analysis and research. **Tactical risk assessment** refers to the objective methods for quantitative risk assessment developed for assessing adverse effects of factors such as chemicals, or planned industrial developments (Beer and Ziolkowski, 1995). These assessments can be applied to determining environmental standards.

It is almost impossible to provide a completely objective measure of risk. However, provided that information is available, it is possible to calculate the risk (e.g. an accident to an individual). This is referred to as the actual risk. In contrast, there are many areas where information is not available for calculating the estimated risk. In these cases risk is often estimated based on opinion, sometimes expert opinion, which is both subjective and based on levels of uncertainty. This can be described as subjective risk.

4.2 Risk assessment and analysis methods

The objectives of risk analyses are to identify the source of risk, the likelihood of occurrence and the magnitude of the consequences. The process involves application of structured, systematic approaches to risk evaluation (OGTR, 2005). Analyses can be qualitative or quantitative depending on the type and quality of data or information available, and the costs of undertaking the analyses.

Qualitative analyses utilise relative descriptions of likelihood and consequences and are generally based on best estimates and expert opinions. The advantages of qualitative analyses include the low requirement for data and the relative ease and low time commitment to undertake. Their disadvantages are that they: are prone to high levels of subjectivity; make predictions that cannot be scientifically tested; are difficult to ensure repeatability and to determine uncertainty (Hayes, 2002a,b; Suter, 1993a; Beer and Ziolkowski, 1995). Precautions can be taken to overcome the weaknesses associated with qualitative assessments (Burgman, 2005; OGTR, 2005). For example, subjectivity can be reduced by quality control measures such as internal and external review procedures (OGTR, 2005). Development of testable and repeatable scientific evidence to support the qualitative estimates of likelihood and consequence will also lead to improvements.

Quantitative risk assessments require a very clear analysis of what is understood and what is unknown. They employ numerical values arising from a range of sources including experimental and historical data. In some cases data from related systems may be employed or data inferred from models. The advantages of quantitative risk assessment are that they incorporate high levels of objectivity and independence from assessors and include probabilistic expressions of uncertainty and produce predictions that can be scientifically tested (Hayes 2002a,b; Suter, 1993a; Beer and Ziolkowski, 1995; Hart *et al.*, 2003; OGTR, 2005). They also enable incorporation of estimates of uncertainty (OGTR, 2005). Quantitative risk assessments can more easily compare multiple risks and alternative management strategies (risk-benefit analysis). They are also more transparent and repeatable. The disadvantages of quantitative risk assessments are that they require more data and numerical and modelling skills, and are difficult to use when there are insufficient or poor quality data. The utilisation of quantitative estimates can also lead to overconfidence.

Risk analysis consists of a set of tools that can be applied to areas where uncertainty is present. The basic elements of the classical approach to risk analysis involves developing a model of the system being analysed, identifying suitable risk indices, estimating unknown parameters and using the model to generate an estimate of the risk indices.

Development of good conceptual models of the risks and systems is an essential first step in risk assessment (Suter, 1993a; Beer and Ziolkowski, 1995; Hayes *et al.,* 2002a,b; Hart *et al*., 2003). There are a range of procedures for developing these concept models. The simplest form is a diagram linking the elements of the systems components used to identify important aspects of the problems including spatial scale, available data, and causal relationships. An example of this is an Influence Diagram (Figure 4.1) showing conceptual relationships among systems components (Hart *et al*., 2003). The conceptual models are developed with input from background information, experts and stakeholders. The model provides the basis for identifying hazards and developing mathematical and statistical models.

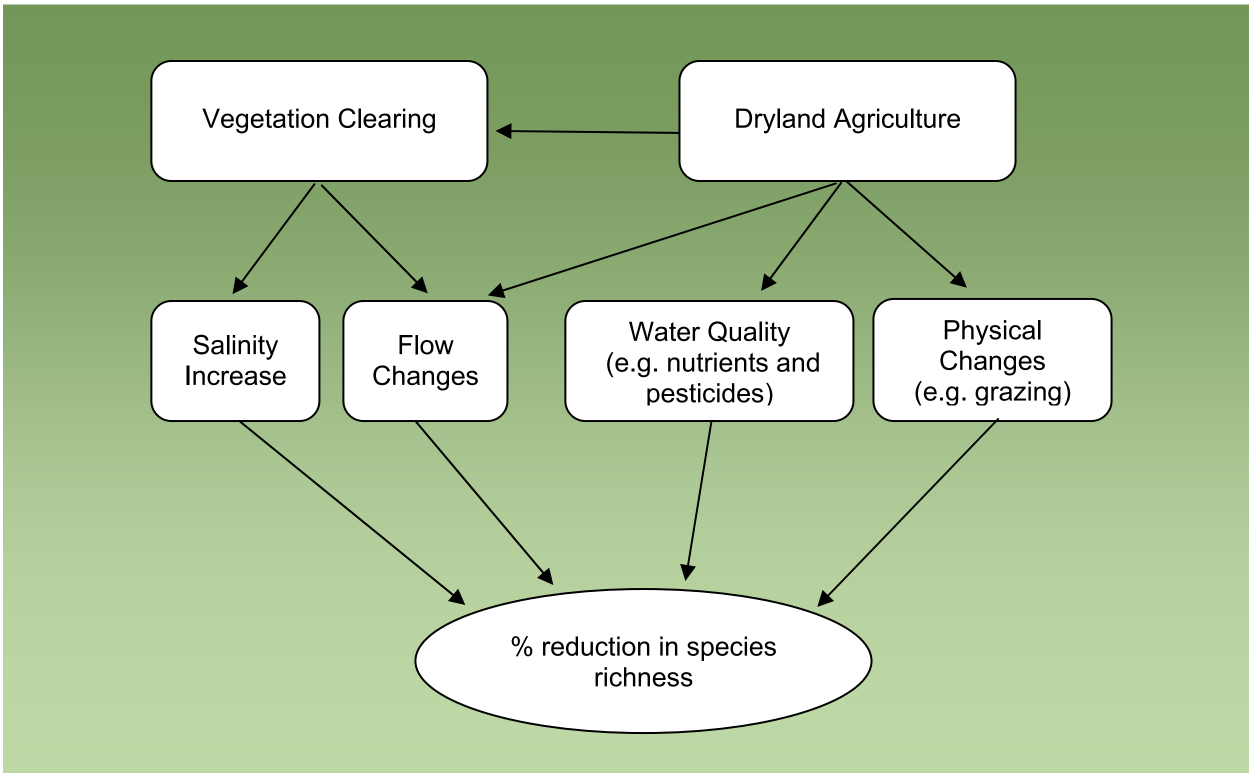

Figure 4.1 Influence Diagram showing conceptual relationships among systems components for determining ecological risks to aquatic systems from salinity increases (Hart *et al*. 2003).

4.2.1 Identification of hazards, components and pathways

A critical part of the process is identification of the hazards and the requirements for a systematic, rigorous approach. There are a number of procedures that have been developed for identifying hazards most of which have been developed by industry for safety or reliability systems. In recent times these have, however, been tested for their applicability in biological and ecological risk assessment. Hayes (2002a; 2004) and Burgman (2005) have identified these procedures:

- **Unstructured deduction** where checklists are developed to identify potential hazards based on previous experiences. Brainstorming, consultation and discussions with stakeholders are employed.
- **Structured induction** uses systematic, logical procedures to identify potential hazards based on identifying all components, sub-components, combinations and operating modes of the systems. The approach involves selection of experts, development of conceptual models and hazards, followed by review and iteration of the models and systems.
- **Fault trees** are employed to link all the processes and events that lead to outcomes or failures. They are employed to identify hazards and design strategies to mitigate them (Kumamoto and Henley, 1996; Hayes, 2002a). A fault tree employs a top-down approach identifying a failure or fault and identifies all the causative events leading to the failure (Figure 4.2; Hayes, 2002a). An Event Tree is a similar procedure with a bottom up approach with the primary event specified and the consequences of the primary event traced forward.
- **Hazard and Operability Analysis** (HAZOP) involves a structured, open ended procedure designed to assist groups of experts to develop a conceptual model of the system (Lihou, 2002). Structured brainstorming of groups of experts guided by facilitators is a common element. It is a bottom up, process orientated approach to identify potential hazards. It has commonly been used for biotechnology (e.g. GENHAZ).
- **Failure Modes and Effects analysis** (FMEA) was developed to improve safety in the aerospace industry and have been employed in petrochemical and motor industries. It is a bottom up approach which examines the consequences of failure in components of a system. FMEA calculates a risk priority number (RPN) for each hazard based on severity, occurrence and detection. The RPNs are used to establish rankings and priorities for actions on hazards. This model has been adapted to investigate the potential spread of biological organisms and is described as "Infection modes and effects analysis" (Hayes, 2002b).
- **Hierarchical Holographic Modelling** is a structured model of complex systems consisting of coupled sub-systems (e.g. biological components, biological processes, physical components, physical processes, chemical components and processes, man made components and processes) within a hierarchy that interacts in non-linear ways. The process accepts that different conceptual models are possible for the system, and aims to encompass many perspectives and disciplines. The model has been employed to identify hazards for introduction of GMOs (Hayes *et al*., 2004).

Risk management requires flexible graphical and mathematical models, supported by appropriate computer software (Ansell and Wharton, 1992; Chapman, 1992). Classical statistical and mathematical methods are employed if data are available for assigning probabilities (Poisson distribution or Bayesian analysis). There have been significant advances in methods of multivariate analysis of risk factors in recent years (Ansell and Wharton, 1992) particularly discriminant function analysis. Many computer programs have been developed for risk engineering. There are two major types: those based on Monte Carlo procedures, and others on specific model or technique based software such as GERT, PERT @ RISK (Chapman, 1992).

Although risk management models and software provide tools for analysis of risk the process of risk assessment still depends on specialist expertise. Successful risk management requires good models and methods that are well linked and appropriate for the project (Chapman, 1992). The success also requires experienced leaders to design and integrate models, methods and software, and to organise and manage teams for successful execution and completion of projects.

4.2.2 Risk assessment and uncertainty

Uncertainty is present in many aspects of risk assessment including risk analyses, hazard identification and risk management. The importance of recognition or estimations of uncertainty in risk assessment is widely recognised (Suter, 1993a; Burgman, 2005; OGTR, 2005). While outcomes in risk assessments may be well characterised there is often a lack of information to determine the probability (likelihood) of them occurring. Uncertainty in risk assessment includes lack of knowledge or information (ignorance), uncertainty about the calculations of risk and model uncertainty (error), and uncertainty due to randomness (stochasticity) of events, systems or processes (Suter, 1993a). There are also problems with the meanings of words or linguistic uncertainty; and in areas involving the use of "expert opinion" or "assessors" and their ability to estimate risk (Burgman, 2005; OGTR, 2005).

There are processes that can be employed to reduce uncertainty. The quality of the information being employed for risk assessment can be assessed and weighted. For example, quality of data can range from a low weighting for unsubstantiated statements to higher weightings for general biological principles, followed by peer reviewed research, published papers and major published reviews of research.

4.2.3 Risk ranking and scoring systems

Risk ranking is a common form of risk assessment that employs predominantly qualitative estimates of likelihood and consequence (Suter, 1993a; Burgman, 2005). The procedure relies on scoring systems for prioritising hazards and assessing risk. It uses scores and subscores for components of likelihood and consequence, some may be quantitative (e.g. rainfall) and others qualitative (e.g. habitat quality) (Suter, 1993a,b). The risk ranking procedures rely on experts to estimate qualitative values and are thus affected by subjective judgements. Risk ranking depends on good conceptual models and hazard identification and assessment. The method has weaknesses due to uncertainty and if methods to maximise reliability are not applied (Burgman, 2005).

Generally the rules and scales employed for scoring systems have been somewhat arbitrary so the potential for bias is high. Problems with the scoring approach include weightings to assess relative importance, scaling (e.g. arithmetic and logarithmic) and procedures for combining scores (e.g. addition and multiplication) (Suter, 1993a). These problems thus have the potential of unintentionally biasing results. Scoring systems therefore need to be assessed adequately for their assumptions and scoring biases before being applied generally (Suter, 1993a).

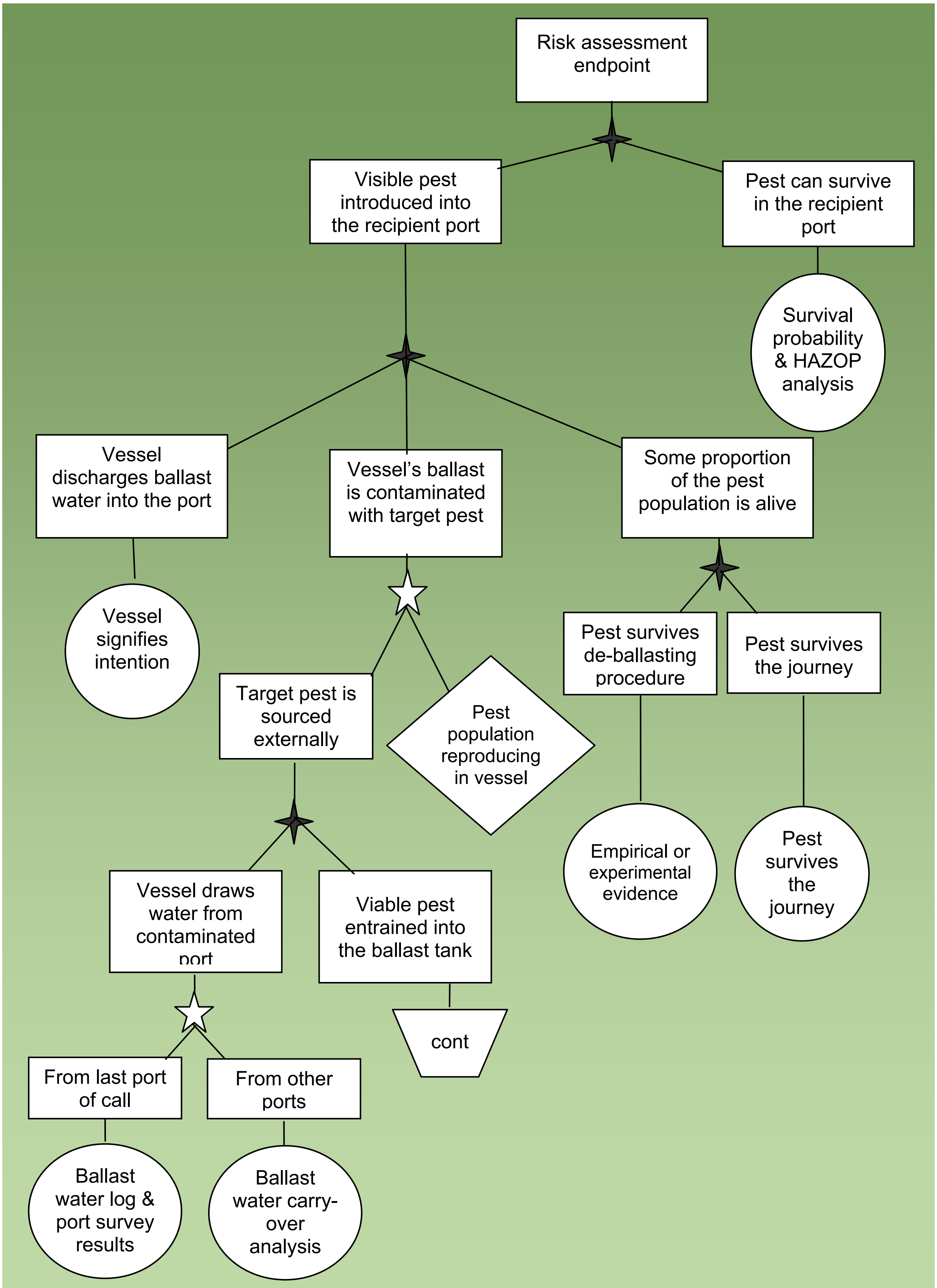

Figure 4.2 A fault tree identifying causative events leading to introduction of pests in ballast water (Hayes, 2002a).

4.2.4 Expert opinion in risk ranking and assessments

Expert opinion is often relied upon when there is an absence of data or quantification is unfeasible. Experts can, however, provide very different assessments on the same question or topic (Suter, 1993a; Burgman, 2005). Methods have been developed for dealing with expert judgements. They include defining the experts and the requirements of skills and knowledge, selecting and training the experts, eliciting information, evaluating the reliability of the information, combining information from different experts and utilising the information for estimations, calculations or decisions (Burgman, 2005).

A method for risk ranking incorporating procedures to maximise reliability, minimise bias and incorporate expert opinion has been recommended by Burgman (2005). A summary of the method is shown in Table 4.1.

Table 4.1 Method for Risk Ranking (after Burgman, 2005).

Stage	Actions
Context and background	Review background information, identify experts, stakeholders. Develop working models, guidelines-send to participants.
Meeting 1	Develop conceptual models. Identify hazards. Define terms (e.g. likelihood and consequence). Training for estimating probability. Individuals rank hazards and risks.
Meeting 2	Discuss differences in ranking. Clarify ambiguities. Refine conceptual models and hazard identification. Individuals re-rank hazards and risks. Combine and present rankings. Detail remaining uncertainties. Assess sensitivity of rankings. Identify data collection and detailed analysis required.
Post meeting	Data collection and detailed analysis.
Meeting 3	Revise conceptual model and risk rankings based on data collection.

4.3 Risk assessment in various fields

Risk assessment was originally developed as a scientific disciplined way of assessing risk for mechanical problems such as chemical or nuclear plants where parameters and systems are clearly defined. They represent well defined and deterministic processes. Risk assessment is also a major component of business risk being applied to areas such as investments, operational, financial, technological, economic risk, business and project management. In the human health area, risk assessment has been applied to the risk assessment and analyses of major epidemics of the 20th century.

Risk assessment procedures have also been applied to areas of cultural heritage. An example is the evaluation of the risk of loss or deterioration of objects or collections developed for museums, galleries and libraries (Artlab, 1999). The assessment was required to inform managers about what factors are putting the collections at risk and to provide the basis for effective strategies and management for maintaining the collections and objects.

The role of risk assessment has developed beyond well defined systems to problems such as environmental factors where there are limitations on the available knowledge. In producing analytical models of environmental risk problems many of the important parameters can only be estimated by surrogate variables.

Ecological risk assessments have been employed to assess the likelihood and consequences of the adverse effects of human activity, contaminants and natural events on flora and fauna communities and ecosystems (Barnthouse and Suter, 1986; Suter, 1993b; Burgman, 2005). Ecological risk assessments have focused on the effects of single contaminants such as pesticides, heavy metals and toxic organic chemicals on the species (e.g. species of plants, fish and invertebrates) inhabiting the impacted ecosystems. Recently, however, there has been a focus on assessing risks to ecosystems and communities (Suter, 1993a; Hart *et al*., 2003; Carey *et al*., 2004; Burgman, 2005).

The potential effects of introduction of exotic organisms have also lead to the development of risk assessment procedures and requirements. Many of the most severe effects on biodiversity and communities have resulted from the introduction of exotic organisms. Exotic organisms include domestic species, non-native game and fish, and other introduced taxa (Bomford, 1993; Suter, 1993a; Hayes, 2002a,b; 2004). Risks posed by development and release of GMOs have been assessed and evaluated using risk analyses and assessments (DETR, 1999; DEC, 2001; OGTR, 2005).

4.4 Risk assessment in natural resource management (ecological risk assessment

Fundamental issues in conservation planning and natural resource management involve the evaluation of the loss or degradation of conservation and biodiversity values. Risk assessment can be employed to determine the best management and strategies to minimise risk, and prioritise limited resources for the best outcomes. Risk assessments have been developed to estimate the risk of human activities, and other threatening processes (e.g. pest plants and animals, inappropriate fire regimes and climate change) on flora, fauna, communities and ecosystems (Barnthouse and Suter, 1986; Suter, 1993a; Hart *et al*., 2003). Analyses can assess the likelihood and extent of effects and thus provide a basis for comparing and prioritising risks so that managers can make informed decisions.

The benefits of undertaking risk assessment in natural resource management that have been identified include: transparency of the process; clear documentation (so that changes in personnel or advances can be applied to work undertaken previously); informed decision making; input into priority setting; and reduced costs for environmental practitioners using standard methods (Beer and Ziolkowski, 1995; Burgman, 2001; Carey *et al*., 2004).

There are a number of problems facing ecological risk assessments. Lack of quantitative data is a major problem, so that many of the models of stressor affects on values are semi quantitative with descriptive ratings for assessing risk. These assessments are thus faced with subjective influences and also high levels of uncertainty (Burgman, 2002; Hart *et al*., 2003; Carey *et al*., 2004). Many ecological risk assessments focus on single species and stress factors, however, when dealing with risk to communities there are increased complexities (Beer and Ziolkowski, 1995; Hayes, 2002a,b).

Another problem is whether the values of the benefits of ecological risk assessments are likely to exceed the costs of implementation (Beer and Ziolkowski, 1995). Quantitative risk assessment requires costs and capabilities, often including systems analysis for scenario development, technical expertise to quantify hazards, expertise with statistical and computer modelling skills and the ability to quantify the cost-benefits associated with determining priorities.

Risk assessment processes have been applied in ecosystem management in the United States of America, e.g. Green Bay (Harris *et al*., 1994) and St Croix National Park (Wenger *et al*., 2000). Quantitative risk assessments have been made for fisheries (Francis, 1992; Punt and Hillborn, 1997) and proposed for weeds (Groves *et al*., 2001) and the release of GMOs (Fiskel and Covello, 1985). Risk assessment has also been applied for the assessment of the risk of ballast water introductions (Hayes, 2002a).

An important procedure employed in ecosystem management is population viability assessment (PVA) to determine extinction risks to threatened and endangered species and populations (Lacy, 1993; Lindenmayer *et al*., 1993; Burgman and Lindenmayer, 1998). PVA is a mathematical modelling tool for assessing the viability of populations of species and predicting the likely outcome to small populations over time. Population parameters are estimated from the field plus known or predicted frequencies of stochastic events. Simulation of the extinction processes are used to assess the short- and long-term viability of populations. If the probability of extinction is unacceptably high then management strategies can be introduced. Spatial models are also available and can be linked to population models (Lindenmayer and Possingham, 1996). The models been adapted for risk assessment and can also be used to assess alternative management strategies, based on estimated risks and the ability to reduce risk (Lacy, 1993; Lindenmayer *et al*., 1993; Burgman and Lindenmayer, 1998; Beissinger and McCullough, 2002).

4.4.1 Risk assessment for biological invasions

Many of the most severe effects on biodiversity and communities have resulted from the introduction of exotic organisms such as domestic species and other introduced taxa (Bomford, 1993; Suter, 1993a; Hayes, 2002a,b; 2004). The potential effects include: reduction in populations of organisms by pathogens; parasitism or predation; changes in the composition or production of the community due to changes in physical and chemical characteristics (pH and soil structure); changes in the community due to habitat changes; and competitive displacement of species (Suter, 1993a).

The potential detrimental effects of introduction of exotic organisms have also lead to the development of risk assessment procedures and requirements. Methods for risk assessment for exotic organisms have been based on those developed for toxic chemicals and industrial systems (Suter, 1993a; Hayes, 2002a,b). Although there is an analogy between complex engineering systems and ecological systems there are some significant differences particularly related to uncertainty and unpredictability. The identification of the agent (e.g. a microbe) is often difficult and attributes of its release (e.g. the source) can be difficult to determine. In addition, biological stressors are not governed by the same decay rates as chemicals.

In recent decades, concerns have been raised that the release of transgenic plants into natural and agricultural environments could lead to significant damage. Rigorous ecological risk assessment is required to determine whether a GMO will be released into the environment (OGTR, 2005).

4.4.2 Assessment of ecological attributes

In undertaking ecological risk assessments we need to have an understanding of what is at risk, and factors in the ecosystems and communities under threat from stressors should be measured. In recent times, the focus has shifted to ecosystems management rather than concentrating on single species. Measures include assessments of biodiversity, ecosystem condition and ecosystem services. These measures may be useful for ecological risk assessments and applicable to the assessment of effects of *P. cinnamomi* on species, communities and ecosystems.

a) Biodiversity

The maintenance of biodiversity is fundamental to maintaining ecosystems, and is currently an environmental priority of Federal and State Governments in Australia. The term biodiversity has been interpreted as species richness, but it has more recently used to refer to the fundamental levels of organisation including ecosystems, the species (all life forms) and the genetic composition (Noss, 1990; Saunders *et al*., 1998). There are many direct (e.g. species richness) and indirect or surrogate (e.g. cover, nutrient cycling and biomass) measures of biodiversity, and the use of multiple measures to assess biological integrity is recommended (Noss, 1990; 1991), including a range of different indicators for monitoring biodiversity (Noss, 1990; Saunders *et al*., 1998). Noss (1990) defined the different attributes; composition, structure and function, at different hierarchical levels at the regional or landscape level down to the genetic level (Table 4.2).

Table 4.2 Hierarchical levels of attributes for different indicators for monitoring biodiversity (Noss, 1990).

Level of organisation	Attributes of biodiversity		
	Composition	**Structure**	**Function**
Regional/landscape	habitat types	heterogeneity and connectivity	nutrient cycling and patch persistence
Community/ecosystem	species richness	vegetation biomass and canopy	biomass and patch dynamics
Population/species	cover and abundance	dispersion and population structure	metapopulation dynamics and fertility
Genetic	allelic diversity	effective population size	genetic drift and inbreeding

Other approaches have utilised combined factors to produce indices. Examples of these include: Simpson's diversity (Simpson, 1949); the Index of Plant Community Integrity (DeKeyser *et al*., 2003) which uses principal components and cluster analyses of species richness and percentage of introduced species; the Floristic Quality assessment (Lopez and Fennessy, 2002) which assesses condition based on expert knowledge; and Vegetation Condition (Leversha *et al*., 2001) a rapid assessment technique for assessing ecosystems.

b) Ecosystem condition and services

The term ecosystem service was employed originally by Ehrlich and Ehrlich (1981) to describe the essential services that natural ecosystems supply to support human life. There have been a number of different definitions and categorisations of ecosystem services

(Cairns and Pratt, 1995; Daily, 1997; Norberg, 1999). The types of services include purification of air and water, maintenance of atmosphere, hydrological cycles, nutrient cycling, generation of soil and soil fertility, provision of habitat, maintenance of biodiversity, provision of food, raw materials and intangibles such as provision of aesthetic beauty, recreation and eco-tourism. Ecological risk assessments may need to incorporate the risk of each of the stressors to these services and conditions.

The choice of measures for ecological risk assessment depends on the aim of the assessment. They are also often influenced by impediments such as expense, time and the complexity of ecosystems that mitigate against paramaterisation within time frames (Suter, 1993b).

4.4.3 Disturbances and resilience

Risk assessment should assess the resistance and resilience of communities, and the capacity for restoration. Disturbances disrupt community structure by changing factors such as the availability of substrates and resources. They also produce alterations to the physical environment including factors such as temperature and climate. They can be classified as exogenous disturbance, such as land clearing, or endogenous disturbance, resulting from biological interactions such as predation. There are differences in the response of communities and taxa to different forms of disturbance. For example, the regeneration of alpine vegetation after land clearance will differ from that following fire. In addition, each ecosystem or community will exhibit different responses to a given disturbance factor (e.g. different responses of rainforest or heathland to fire).

The process of restoring structure and function after a disturbance is considered the resilience of the community (Westman, 1986). This involves the degree, manner and pace of restoration (Westman, 1986). The ability of the biotic components of an ecosystem to withstand disturbances, such as salinity increases, depends on the resilience and resistance of the system's components under their current condition (Scheffer *et al*., 2001; Walker *et al*., 2002). Resistance can be defined as the capacity of the system to resist change in structure and function. Resilience represents the capacity of a system damaged by disturbance to return to its prior state if the disturbance is removed (Peterson *et al*., 1998; Carpenter *et al*., 2001).

4.4.4 Goals for environmental risk assessment

The values that require protection and the goals or aims can be viewed at different levels (Suter, 1993a):

- Management goals - define broad objectives (e.g. a healthy ecosystem), have policy and social support.
- Assessment endpoints - describe the management goals (e.g. a healthy ecosystem -defined as maintenance of flora and fauna species, populations and communities and ecological processes).
- Measurement endpoints - describe values that can be measured (e.g. abundance and distribution of species, presence of disease).

Risk assessments need to address all levels to satisfy ecological, policy, social and political requirements.

4.4.5 Risk assessment in Australian natural resource management

In Australia, natural resource managers possess few tools to assist them in determining the risk of adverse affects of threatening processes, and what is required to minimise the risk. Risk management has not been employed to a great extent for natural resource management although agencies have applied risk management assessments to occupational health and safety (Carey *et al*., 2004). Qualitative risk assessment methods have been applied to the Western Australian rock lobster fishery (IRC, 2002) and the effect of shellfish farming on marine environments in Tasmania (Crawford, 2003). Risk assessments have been undertaken for biological invasions including marine pests in ballast water (Hayes, 2002b), and the importation and keeping of exotic vertebrates (Bomford, 1993). A decision analysis approach to risk assessment and determining priority actions for sustaining biodiversity was employed by Possingham *et al*. (2002) for setting Australia's biodiversity priorities. The process outlined the current risk to biodiversity of each major threatening process identified in national objectives and targets for Biodiversity Conservation 2001-2005. The analysis involved choosing between options by quantifying the costs and benefits of particular actions and calculating biodiversity benefits. A cost-benefit analysis was secured for each option, and collateral effects were described.

4.5 Databases for *Phytophthora* dieback available across Australia

Key components for risk assessment and management of *Phytophthora* dieback are to know: where it occurs, which species and communities are threatened, and what the risks and consequences of infestation are. The databases and information needed to develop risk assessment processes were reviewed in this document on a state by state basis. The quality of the information, the collection and management of the information were assessed.

4.5.1 Positive isolations, mapping and database records of the current known active range of *Phytophthora cinnamomi*

The distribution of *P. cinnamomi* in Australia has generally been assessed as locality points of infestation (Podger, 1999) except in Western Australia where large areas have been mapped. Mapping the extent of disease caused by *P. cinnamomi* in Australia is considered to be a difficult goal to achieve, but not impossible. The spread of the pathogen by both autonomous and passive modes are considered to be ongoing processes that make large-scale mapping inaccurate after a period of time (Podger, 1999). There are only two States (South Australia and Tasmania) where a single database holds records of *P. cinnamomi* isolation throughout the State. There are different databases in each State making it difficult to assess the extent of *P. cinnamomi* infested land in Australia.

In Western Australia, the Department of Conservation and Land Management's (CALM) Forest Management Branch has the only database of records of *P. cinnamomi* known infestations in the forest estate. The Vegetation Health Services of CALM keep the positive isolation records for *P. cinnamomi*. Mapping is usually undertaken within 12 months of any operational activity on CALM land (CALM, 2000). Trained interpreters analyse photos taken at 1:4500 to demarcate infection boundaries. These interpreters assess disease symptoms to draw conclusions about the health of the vegetation. *P. cinnamomi* Occurrence and Protectable Areas maps are prepared with uninfested, uninterpretable, infested and unprotectable areas classified. Field visits to view the symptoms and sampling of recently dead plants are used to verify the interpretation of aerial photographs. CALM retains the records along with GIS co-ordinates. In March 2004, Western Australia's environment minister announced a project for the development of a West Australian Dieback Atlas. This is in progress and is anticipated for release in mid 2006.

Other organisations that contribute to mapping *P. cinnamomi* in Western Australia are mining companies in the south west, Murdoch University, the Dieback Working Group and the South Coast Regional Initiative Planning Team (SCRIPT). Dieback management programs have been implemented by Alcoa World Alumina, Australia Limited in the bauxite mining operations in the jarrah forest south east of Perth, and by RCG Mineral Sands Limited at mineral sands operations at Eneabba on the Swan Coastal plain 300km north of Perth (IJ Colquhoun, *pers. comm.*). A major component of these programs includes surveys, dieback mapping and interpretation. All samples are sent to the Department of Conservation and Land Management for testing. Murdoch University's CPSM hold internal records of *P. cinnamomi* isolations. The Dieback Working Group has been mapping *P. cinnamomi* in reserves in the metropolitan area and is beginning to do more now on the south coast of Western Australia. The SCRIPT project is currently producing a disease map based on aerial photos and isolation data from CALM's Vegetation Health Service database.

In South Australia, the distribution of *P. cinnamomi* and other species of *Phytophthora* has been mapped on a state-wide, regional (Mount Lofty Ranges) and local scale (catchments or reserves). The Department for Environment and Heritage is the custodian of information for all lands. Details of symptoms, isolation and GPS are held in a database. The *Phytophthora* database is administered and distributed by the Ecologist - Plant Dieback (R Velzeboer) and data points are validated by the GIS Officer. Other organisations contributing to the database include; South Australian Research and Development Institute, Primary Industries and Resources, Transport SA, Councils, Forestry SA and SA Water.

In Victoria, the Forest Pathologist of the Department of Sustainability and Environment maintains a database of records. However, principals of research groups also hold their own records (for example, D Cahill of Deakin University). All records were reviewed and combined in 2002 (Gibson *et al*., 2002). Distribution mapping of *P. cinnamomi* has been undertaken in few parks or reserves, and in most cases only to a limited extent. Such mapping has been undertaken in the Brisbane Ranges National Park (Peters, 1995) and initiated at Wilson's Promontory, Otway and Angahook-Lorne National Parks (Bluett, 2001; Cahill *et al*., 2001a,b,c). The land area affected by *P. cinnamomi* in parks is currently restricted. Mapping *P. cinnamomi* distribution in individual parks and reserves is thus likely to be achievable if required for management purposes (Gibson *et al*., 2002).

The distribution of *P. cinnamomi* in Tasmania is based on soil sampling by Forestry Tasmania who has isolation data since 1972. Specialist surveys to detect and map field symptoms of *P. cinnamomi* are offered to forestry, mining and civil engineering companies. A record of samples tested and the results are on the pathology database with a high proportion of the test results linked to map co-ordinates (T Wardlaw, *pers*. *comm*.). The Department of Primary Industry, Water and Environment (DPIWE), Tasmania collects symptom and isolation data. Within general areas of *P. cinnamomi* infection there is a mosaic of infected and uninfected patches (Schahinger *et al*., 2003). Aerial mapping is only useful in grass tree dominated communities in Tasmania because the scale of photography precludes interpretation of disease symptoms (T Rudman, *pers. comm*.). Distribution records consist of symptom polygons assessed visually by trained observers. Polygon boundaries are arbitrary and are generated on extent of infection observable on the route taken by the observer (T Rudman, *pers*. *comm*.). The database to which Tasmanian Parks & Wildlife Service, DPIWE and Forestry Tasmania contribute information on isolations is located in the GTSpot database at http://www.gisparks.tas.gov.au/

In New South Wales, there is no state-wide funding set aside for the mapping of *P. cinnamomi* infections. However, the Sydney Harbour Dieback Working Group, including Local, State and Commonwealth Government land managers in the Sydney Harbour region, studies areas to determine where *Phytophthora* occurs and what actions can be taken to control it. A management strategy is being implemented that includes mapping and monitoring infected and uninfected areas (Sydney Harbour Trust Fund, 2004).

Mapping the distribution of *P. cinnamomi* in the Wet Tropics World Heritage Area (WTWHA) of Northern Queensland is funded by the CRC for Tropical Rainforest Ecology and Management. Aerial photography is used to identify dieback polygons, which are patches of apparent canopy death or thinning. These areas, ranging from 1 to 10ha or more, are mapped onto a GIS layer. Dieback polygons delineate locations in which smaller patches of dead and dying canopies can be detected (Gadek and Worboys, 2003). High resolution videography obtained using low flying aircraft and the multispectral imaging and digital image analysis are used to examine and map the distribution of *P. cinnamomi*. Distribution of *P. cinnamomi* has been documented in the WTWHA by Brown (1976; 1998), and in the Mt Lewis and Tully Falls/Koombooloomba Dam in the far north by Abell and Gadek (2003).

4.5.2 Laboratory detection services

Due to the low volume of requests there are relatively few laboratories in Australia offering diagnostic services for isolation of *P. cinnamomi*. As the cost of testing is high, throughput does not increase, thus maintaining low volume of testing and high costs (Table 4.3). For example, Forestry Tasmania have processed an average of 65 soil baits/year for the last 5 years (T Wardlaw, *pers. comm*.) and in 2003 there were approximately 80 requests for *Phytophthora* testing sent to the Plant Disease Diagnostic Unit of The Royal Botanic Gardens of Sydney, New South Wales (Royal Botanic Gardens and Domain Trust, 2003).

Most laboratories are still using morphological diagnostics only, while molecular tests such as PCR (Drenth *et al*., 1998) and real time PCR are available (Vandemark, 2003; Belbahri *et al*., 2005). A PCR diagnostic test, developed by the CRC for Tropical Plant Pathology, Queensland is available in kit form and could be used as a standard diagnostic tool in laboratories.

Most of the diagnostic services provided to private clients are confidential so positive isolations of *P. cinnamomi* are not available for database entries (for example, in Western Australia; the Department of Agriculture and Curtin University's Department of Environmental Biology). Very few of the laboratories are accredited. The Department of Primary Industries of NSW Plant Health Diagnostic Laboratories has NATA accreditation for *Phytophthora* baiting and the West Australian Department of Agriculture Diagnostic Services are actively working toward NATA accreditation.

4.5.3 Vegetation vulnerability mapping

In order to strategically prioritise management and funding vulnerable vegetation needs to be identified. This is generally tackled area by area in each State.

In Western Australia, the South Coast Regional Initiative Planning Team (SCRIPT) project commenced in 2004 to establish a methodology for the development of landscape scale threat assessment maps relevant for all Western Australian bioregions and of assistance to managers in other States. The first aim of this project is to apply that methodology within a pilot region on the South Coast, and then to develop costing and guidance for adoption of the methodology in other regions. This will result in the recognition of areas of critical importance for protection against introduction of *P. cinnamomi,* particularly areas of high biodiversity that are at risk (SCRIPT, 2004).

In South Australia, the Department for Environment and Heritage produced a regional map "native vegetation at risk of *Phytophthora* in the Mount Lofty Ranges". The vegetation types affected by *P. cinnamomi* (i.e. where *P. cinnamomi* and susceptible plant species are present) were identified. These data were extrapolated to the areas elsewhere in the region where those vegetation types existed. Vegetation types potentially at risk from *P. cinnamomi* infestation were also identified as they contained susceptible plant species, but *P. cinnamomi* had not been recorded in those vegetation types. *High Risk Areas* are defined as areas where *Phytophthora* is known to be present or is likely to become established based on rainfall. These include The Mount Lofty Ranges, Fleurieu Peninsula and Western and Central Kangaroo Island. *Moderate Risk Areas* are areas where Phytophthora has not been recorded but which have the potential for *Phytophthora* to become established. This includes the Southern Eyre Peninsula, South East and Eastern Kangaroo Island. *Low Risk Areas* are where it is unlikely that *Phytophthora* would become established and encompass all other areas of South Australia (Phytophthora Technical Group, 2003).

In Victoria, a list of species considered to be susceptible to *P. cinnamomi* infection was compiled (Gibson *et al*., 2002). The Victorian Flora Information System (FIS) was used as the primary source of information for the distribution of the species. The FIS is comprised of comprehensive floristic quadrat data for all vegetation work undertaken in Victoria and is based on five minute grid cells. The distribution of sites where the susceptible species have been recorded was mapped for the State. The total number and average number of susceptible species recorded per grid cell were calculated and mapped. The average number of susceptible species per quadrat was used to classify risk from *P. cinnamomi* as low (<3), medium (3-6) and high (>6). The total number of susceptible species recorded per quadrat was averaged for all quadrats in each Ecological Vegetation Class and mapped. Those with high average numbers of susceptible species were; heathy woodland, herb-rich heathy forest; heathy dry forest; sand heathland, clay heathland and wet heathland (Gibson *et al*., 2002).

Podger *et al* (1990) undertook a bioclimatic analysis of the distribution of positive and negative records for *P. cinnamomi* in Tasmania to identify those areas climatically suitable for disease (rainfall >600mm and mean annual temp >7.5 °C). Within this envelope Schahinger *et al*. (2003) identified the vegetation communities susceptible to *P. cinnamomi* based on species susceptibility, disease records, microclimate influences (e.g. closed canopies prevent disease development in Tasmanian wet or damp forests and rainforests) and soils (e.g. alkaline soils are suppressive). Each community was classified as highly susceptible, moderate or variably susceptibility or low susceptibility. Tasmania has a state-wide vegetation map (TASVEG) of a scale and accuracy useful for land managers (1:25,000). The TASVEG vegetation mapping units have been categorised based on their perceived susceptibility to *P. cinnamomi* as highly susceptible, variably susceptible and not susceptible. Susceptibility/vulnerability is based on the number of susceptible species in the mapping unit and the level of change occurring upon infection by *P. cinnamomi* (Schahinger *et al*., 2003). Seventeen mapping units have been categorised as highly susceptible and 32 as variably or moderately susceptible. Low or no susceptibility includes wet forests, rainforests, sphagnum bogs and miscellaneous units including pasture, exotic plants and developed areas (urban and rural). As each mapping unit may include a number of described plant communities there can be variability within a mapping unit. The three categories are intended to support management planning and assist districts to identify areas where *P. cinnamomi* is an issue that needs to be addressed when undertaking operations. Using TASVEG, a *P. cinnamomi* vulnerability map was produced.

In the World Heritage Area of Tasmania all areas of Blanket Moorland have been categorised as highly susceptible.

Table 4.3 Diagnostic services provided in Australian laboratories for the isolation and identification of *Phytophthora cinnamomi* from soil and plant tissue.

State	Organisation	Soil or tissue	Test	Time (days)	Cost/sample ($)
WA	Department of Agriculture Diagnostic Services	soil	Baiting and morphological	7-14	115.00*, 83.00
		tissue	Morphological to genus only	5-14	145.00*, 130.00
	Curtin University Department of Environmental Biology	soil and tissue	Baiting single and double, and morphological	14-28	93.50 (single) 110.00 (double)
	Murdoch University	soil and tissue	Baiting single and double, and morphological	~21	100.00
	Vegetation Health Service of the Department of Conservation & Land Management	soil and tissue	Baiting and morphological tests	n/a	n/a
SA	South Australian Research and Development Institute	soil	Baiting and morphological identification	7-28	71.50 for bulk samples 49.50 for NIASA members
		tissue	Baiting and morphological	7-28	115.50
Vic	Department of Primary Industries, Knoxfield. Crop Health Services				unknown
Tas	Forestry Tasmania	soil and tissue	Baiting and morphological	14	50.00
	Department of Primary Industries, Water & Environment, Diagnostic Services Branch	soil and tissue	Baiting and morphological		unknown
NSW	Plant Disease Diagnostic Unit, Royal Botanic Gardens, Sydney	soil	Baiting and morphological identification	7-10	120.00*, 35.00 20.00 for the home gardener
	Plant Health Diagnostic Laboratories – Department of Primary Industries				unknown
QLD	Department of Primary Industries, Growhelp	soil	Baiting and morphological	5-10	
		tissue	Morphological and molecular	3-7	119.00 87.90 for assoc members

* cost of first test – followed by cost of subsequent tests.
NIASA = Nursery Industry Accreditation Scheme Australia
n/a = not applicable as not offered to public.
Unknown = unable to obtain information

4.5.4 Susceptible plant species (rare and threatened species that are susceptible to *Phytophthora cinnamomi*)

The review by McDougall (Part 2 – National Best Practice Guidelines, Appendix 4) contains a list of over 1000 known native hosts of *P. cinnamomi* in Australia compiled from published material, unpublished records and observations of individual researchers. A susceptibility rating has been assigned to each species where such information is available. Australian States and Territories have also compiled their own lists of susceptible taxa.

In Western Australia, 300 plant species have been listed as susceptible to *P. cinnamomi* (Part 2 – National Best Practice Guidelines, Appendix 4) of which 35 are classed are rare or endangered species (Groves *et al*., 2003), although it was estimated that as many as 2000 plant species of the southwest are susceptible to infection (Wills, 1993). Recently, Shearer *et al*. (2004) has shown that 51% of the 5710 species in the south-west botanical province are susceptible to *P. cinnamomi*.

In South Australia, 29 known native plant species susceptible to *P. cinnamomi* are listed in the *P. cinnamomi* management guidelines (Phytophthora Technical Group, 2003). Six of these plant species are endemic to Kangaroo Island. Early contributions to this list were made by Weste (1981; 1986), and Lee and Wicks (1977).

In Victoria, a list of species considered to be susceptible to *P. cinnamomi* infection was compiled (Gibson *et al*., 2002). The National Threat Abatement Plan (Environment Australia, 2001) lists 6 species in taxa which are considered rare or poorly known in Australia and which are known to be susceptible to *P. cinnamomi*.

In Tasmania, 57 susceptible hosts were identified (Barker *et al*., 1996), 36 were subsequently tested and found to be susceptible. Recently, 109 species were listed as susceptible to *P. cinnamomi* (Schahinger *et al*., 2003). Fifteen susceptible species were listed in the schedules of the Commonwealth EPBCA 1999, and 35 were listed in the schedules of the Tasmanian Threatened Species Protection Act 1995.

There are over 220 plant species in New South Wales that are known to be susceptible to *P. cinnamomi* (Part 2 – National Best Practice Guidelines, Appendix 4). Of these, 17 species are regarded as highly susceptible. The NTAP lists 5 nationally endangered species that occur in New South Wales for which *P. cinnamomi* is a known or perceived threat.

In Queensland, Worboys *et al*. (2003) listed 26 canopy tree species that have been shown to be susceptible to *P. cinnamomi* in the field.

However, several problems arise when trying to define the susceptibility of rare or threatened flora or fauna species. It has been recognised that there is variability between States where a species may be listed as highly susceptible in one State, yet in another it is not recognised as a susceptible species. Susceptibility to *P. cinnamomi* is often based on observations at a low number of sites and the susceptibility of most listed species has not been tested in the laboratory or glasshouse. The actual definition of susceptibility is not clear. Susceptibility is described as species which have high mortality in the field, but should this include 'at numerous sites' and 'resulting in a loss of species from several areas'?

There is a lack of information on the susceptibility of rare and threatened flora and fauna species. The species host list for *P. cinnamomi* produced by McDougall (Part 2 – National Best Practice Guidelines, Appendix 4) indicates the plant species that are listed as Critically Endangered, Endangered and Vulnerable.

Another major problem when identifying threatened species that are susceptible to *P. cinnamomi* is that many species that many be threatened are not yet on any threatened wildlife listings. This is due to the lengthy process involved in adding to these lists. For example, in Western Australia, the Threatened Species Scientific Committee (TSSC) meets at least once a year to consider any nominations received to add taxa to, or delete taxa from the current Declared Rare Flora and Specially Protected Fauna lists. The TSSC then reports to the Executive Director of the Department of Conservation and Land Management (CALM) and the Minister for the Environment. The National Parks and Nature Conservation Authority, established under the CALM Act 1984, also considers the advice of the TSSC and makes recommendations to the Minister on wildlife conservation policies. Ministerial approval is necessary before changes are given legal status in a notice in the Government Gazette.

4.5.5 Susceptible fauna species (rare and threatened species that are susceptible to *Phytophthora cinnamomi*)

Although there has been a substantial number of studies on the effects of *P. cinnamomi* on vegetation there has been little work investigating the impact of Phytophthora dieback on faunal populations and communities. The alterations to vegetation communities caused by Phytophthora dieback are likely to have effects on the endemic fauna through alterations to suitable habitat, for example by changes to protective cover, food resources and nesting sites (Wilson *et al*., 1994; Christensen, 1997).

In Western Australia, the conservation status of Gilberts Potoroo *Potorous gilbertii*, currently listed as Critically Endangered, and the Honey Possum *Tarsipes rostratus* were speculatively connected to *Phytophthora* dieback in a recent review (Calver and Dell, 1998). The density and distribution of the Honey Possum is governed by the availability of nectar and pollen for food, predominantly from proteaceous plants (Garavanta *et al*., 2000; Wooller *et al*., 2000). Successful reproduction in this species is also critically limited by food resources (Wooller *et al*., 1999), so the Honey Possum is very likely to suffer declines in distribution and abundance if *Phytophthora* dieback reduces the availability of its proteaceous food plants.

An analysis of mammals that occur in Victoria found that for 22 species, more than 20% of their range occurs in *P. cinnamomi* affected areas (Laidlaw, 1997; Wilson and Laidlaw, 2001). Five rare or endangered species in Victoria, the Smoky Mouse *Pseudomys fumeus*, the Heath Mouse *P. shortridgei*, the New Holland Mouse *P. novaehollandiae*, the Long-footed Potoroo *Potorous longipes* and the Brush-tailed Rock-wallaby *Petrogale penicillata* have greater than 20% of their distribution in areas susceptible to *Phytophthora* dieback.

In New South Wales, the State Scientific Committee, established under the Threatened Species Conservation Act, determined that *Phytophthora* dieback is a threatening process that directly affects the conservation of endemic populations of the Southern Brown Bandicoot *Isoodon obesulus* and the Smoky Mouse *P. fumeus*. The Long-footed Potoroo is also considered to be at risk from *Phytophthora* impact due to the proximity of recent infections to suitable habitat for this marsupial. Despite a lack of information on the effect of *Phytophthora* dieback on the mammals inhabiting forest communities, the studies reviewed indicate that significant effects are likely.

There has been no substantial work done on the effect of *P. cinnamomi* on the fauna of Tasmania (T Rudman, *pers. comm*.).

4.5.6 Listed threatened communities that are susceptible to *Phytophthora cinnamomi*

There are mechanisms for listing threatened communities at State and Federal level. Under the *EPBC Act* and the EPBC Regulations the Department of Environment and Heritage has defined three categories for threatened ecological communities:

- Critically Endangered - facing extremely high risk of extinction in the wild in the immediate future
- Endangered - facing a very high risk of extinction in the wild in the near future
- Vulnerable - facing a high risk of extinction in the wild in the medium-term future (Department of Environment and Heritage website – Threatened Ecological Communities, accessed 12/7/05).

Threatened communities are listed under the Flora and Fauna Guarantee (FFG) Act, in Victoria and under the Nature Conservation Act in the ACT. In other States, there is no current legislation but processes and databases for assigning ecological communities to categories of threat are in place in some (e.g. Western Australia).

4.5.7 Designated long term monitoring sites

Long term monitoring of dieback affected sites can provide invaluable information about rate of spread of disease, recovery and survival of plant and animal species in the area and the effectiveness of management. While a few different management prescriptions have been utilised in different areas it appears that the effectiveness of specific prescriptions has not been monitored. There has not been any state-wide systematic testing of soil and plant material in order to monitor long-term patterns of infestation intensity, activity and rate of spread. This means that the epidemiology of *P. cinnamomi* in Australia is still poorly understood.

The Department of Conservation and Land Management (CALM) have a range of projects to monitor the spread of dieback in Western Australia. Since 1996/1997 CALM officers have marked the boundaries of a number of fronts near the south coast. They are also monitoring areas sprayed with phosphite where rare flora occurs in the Stirling Ranges and near Albany (S Barrett, *pers*. *comm*.). On the south coast the boundaries of a number of fronts have been pegged at Gull Rock and Two Peoples Bay (M Grant, *pers*. *comm*.). Currently CALM officers are mapping the major infestation site at Bell Track in the Fitzgerald River National Park. This infestation was previously mapped in 1990/1991. The current disease front of the Bell Track has reached the boundary of a poorly defined micro-catchment, and if it spreads to the two adjoining drainage lines a rapid and unchecked spread is predicted with catastrophic consequences for highly diverse, highly endemic flora and the habitat of a number of endangered and critically endangered fauna (M Grant, *pers*. *comm*.).

On a smaller scale, CALM have established stable long term research plots of *Banksia* woodland on the southern west coast between Mandurah and Augusta. These areas of free draining sands are approximately 20 hectares in total. A 16 year monitoring program showed an annual disease extension rate of approx 1 m (C Crane, *pers*. *comm*.).

In the jarrah forest of Western Australia, long term monitoring sites (100 quadrats) were established in 1994-1995 (K McDougall, *pers*. *comm*.). Plots established by F Podger in the 1960s were also remeasured in the mid 1990s. Recent work has assessed the rates of extension in different ecological vegetation systems of the Jarrah Forest Bioregion of Western Australia (Strelein *et al.,* 2005). Sites were measured for movement of disease fronts mapped between 1986 and 1998 in the Darling Plateau (west and east), the Blackwood Sedimentary Plateau and the southern crystalline Plateau. The rates of movement varied but overall upslope was 1.5m/year with incised creeks and watercourses showing the greatest rate. The rate of up-slope movement in the wetter Blackwood Plateau (2.15m/year) was different to the Darling Plateau east (0.37m/year). The higher rate in the latter was predicted to be related to a clay layer, perched water table and poor drainage.

Since 1978, research conducted by Alcoa World Alumina Australia has contributed significantly to the understanding of the spread of *P. cinnamomi* via infected road materials, water sources and on vehicles (Colquhoun and Hardy, 2000). Alcoa continue to monitor any spread that happens adjacent to their mining. This is demarcated in the field and mapped with GPS co-ordinates. All sites are monitored every 5 years (IJ Colquhoun, *pers. comm.*).

In Victoria, long-term studies have been undertaken in the Brisbane Ranges, Wilson's Promontory National Park, Grampians National Park (Weste *et al*., 2002) and Anglesea (Wilson *et al*., 1997). Longer term studies in the Brisbane Ranges and the Grampians have shown chronosequential changes in the floristic composition do occur over time (Weste and Ashton, 1994; Weste *et al*., 2002). Species present in post-diseased areas are likely to be either resistant to *P. cinnamomi*, exhibiting little or no disease symptoms or tolerant/fluctuating species, exhibiting some disease symptoms as well as showing regrowth and recovery at times. Susceptible species (e.g. *Xanthorrhoea australis*) have reappeared by regeneration from seed in the Brisbane Ranges (Weste and Ashton, 1994) and the Grampians (Weste *et al*., 2002). This decrease in inoculum would allow establishment of *X. australis* from soil stored seed, however whether regenerating *X. australis* have been observed to be susceptible to re-infection is unknown. Apart from *X. australis*, no other susceptible species were observed regenerating in post-disease areas in this study. In the Grampians, Weste *et al*. (2002) recorded the return of 30 species in previously infested sites, however, two species failed to survive and six species have not regenerated at all.

In New South Wales, permanently marked floristic quadrats were established in 2001-2002 in infested and healthy areas at Mt Imlay and Mt Sugarloaf in South East Forests National Park (K McDougall, *pers. comm.*).

In Tasmania, there are a number of long term monitoring sites including: heathland and Rock cape and buttongrass moorland at Melaleuca established in 1979 and buttongrass moorland at Red Knoll and Bathhurst harbour established in 1998 (T Rudman, *pers. comm.*).

4.6 Risk mapping and analyses - spatial models

The development of a disturbance-response (conceptual) model of adverse effects of stressors or disturbance factors on the biotic environment is considered to be a major first step for an ecological risk assessment (Hart *et al*., 2003). A macro scale model is part of this process to show where risks are at the landscape or catchment level. The mapping of the distribution of *P. cinnamomi* and the likelihood of infestation is required to determine where the risks are at the landscape and catchment levels.

A range of models of risk mapping that may be applicable for assessing risk of infestation for *P. cinnamomi* in Australian ecosystems have been developed. In recent years, GIS have been employed to investigate distribution and abundance of flora, pathogens and fauna at the landscape level (Lindenmayer *et al*., 1999; Guisan and Zimmermann, 2000; Lauver *et al*., 2002; Rushton *et al*., 2004). Predictive distribution models derived by combining GIS technology with statistical analyses can provide information about the distribution and spatial arrangement of taxa and communities. Models can be generated using species presence or absence as the independent variable and landscape variables, measured on site and extracted from GIS data layers as the predictors. Spatial extrapolation of models can produce maps of predicted suitable sites or habitat for the taxa or communities.

The application of GIS is becoming a valuable tool for managing flora and wildlife in many parts of the world as it provides information at different landscape scales. The models and results are important for management and can be incorporated into environmental decision support system.

Forestry risk mapping

In agriculture and forestry mapping risk of disease and infection is a major component of risk assessment and risk analysis of the current and potential distribution of plant pathogens and other diseases is important. Databases of occurrence records, susceptible species, climate and topography GIS layers can be employed to develop predictive maps of potential future occurrence and of risk of introduction of the disease.

The United States Department of Agriculture and Forests Service initiated a large project mapping risk from insects and diseases in the national forests in 1996 (Lewis, 2002). The purpose of the risk mapping was to help determine where attention needed to be focused to address national forest health. Regional staff throughout the United States used empirical data, models and expert judgement to develop a GIS database, maps and to make risk projections. The risk map provides a visual representation of predicted future tree mortality. Of the 70 million acres at risk, 33 million (47%) were on National Forests, and 37 million (53%) on other lands. Of the 26 insects and diseases evaluated, four groups accounted for more than 66% of the areas at risk (gypsy moth in the East, root diseases in the interior West, southern pine beetle in the South, and bark beetles in the West).

Phytophthora ramorum *in the United States*

A project developing a risk map for the virulent plant pathogen *Phytophthora ramorum,* was developed in 2003 to guide surveys for the pathogen (Shaw and Britton, 2003). *P. ramorum* was discovered in the United States in 2000. The air-borne pathogen known to be the cause of Sudden Oak Death (SOD), spread to forests in 12 coastal California counties and in Oregon. It was also found in nurseries in Washington, Oregon, and British Columbia, Canada. The oak woodlands, urban forests, agricultural, forestry and horticultural industries are threatened because of the pathogen. The pathogen has killed tens of thousands of forest trees, horticultural nursery plants, rhododendron, camellias and other species. In California, it has negatively affected ecosystem functions, increased fire and safety hazards and has been estimated to have major economic impacts.

P. ramorum is classed as a quarantine pathogen and thus, requires maps identifying infestations. Records of the pathogen distribution are maintained in a national web-accessible GIS database and linked to California's SOD database (California Oak Mortality Task Force; www.suddenoakdeath.org). A preliminary risk map was developed by the Forest Health Monitoring Program to guide cooperative pilot surveys in 2003. The risk map was based on potential introductions, susceptible plant species, weather conditions favourable to *P. ramorum* survival and disease development. The analysis predicted that the areas at greatest risk of becoming infested were the Appalachian Mountains, coastal areas of Oregon, Washington and areas of currently uninfested coastal California. Between 2000 and 2003, the annual resource allocation for the National Strategy was approximately $US2.2M (Forest Service Research and Development); $US1.7M (SOD), $US2M (Animal and Plant Health Inspection Service) and several million for the Agricultural Research Services. In 2005, another $US1M was awarded for research, US based and international, to increase the understanding of *P. ramorum*/SOD (USDA Forest Service website - Sudden Oak Death Research, *Phytophthora ramorum*, accessed 12/4/05).

Phytophthora cinnamomi in Australia

Current approaches to risk mapping for predicting the likelihood of *P. cinnamomi* infestation in Australia have been limited and variable. Those that have been undertaken represent analyses undertaken at different spatial scales and for different purposes.

Studies by Wilson *et al*. (2000; 2003) investigated the distribution of *P. cinnamomi* infection in the eastern Otways southern Victoria, a catchment area of significant floral and faunal diversity which has been listed on the National Estate (Australian Heritage Commission, 1993). They aimed to determine the relationship of infection to site variables and to develop a predictive model of infection. Site variables recorded at 50 study sites included aspect, slope, altitude, proximity to road and road characteristics, soil profile characteristics and vegetation attributes. Soil and plant tissues were assayed for the presence of the pathogen. The pathogen was isolated from 76% of the study sites.

GIS was employed to provide accurate estimations of spatial variables and develop a predictive model for the distribution of *P. cinnamomi* (Figure 4.3). A spatial GIS database of several themes was developed to support: i) mapping; ii) accurate estimation of spatial variables such as elevation, slope, sun-index and contributing catchment area; and iii) spatial extrapolation of regression models for the probability of the presence of *P. cinnamomi*.

Of the 17 site variables initially investigated during the study a logistic regression model identified only two, elevation and sun-index, as significant variables in determining the probability of infection. The presence of *P. cinnamomi* infection was negatively associated with elevation (i.e. the lower the elevation, the more likely the presence of the pathogen) and positively associated with the sun-index (i.e. places which have a steep northerly aspect). These findings are consistent with the down-hill spread of zoospores with free water movement and suggest that within the mid-elevations of the catchment, the warmth associated with northerly aspects is conducive to *Phytophthora* activity.

The logistic regression model was spatially extrapolated over the study area and predicted that up to 74% of the study area (11 875ha) had a high probability of being affected by *P. cinnamomi*. Such studies provide a powerful tool to initiate management strategies.

A project currently being undertaken in Western Australia by the South Coast Regional Initiative Planning Team (SCRIPT) is "*Phytophthora cinnamomi*: Mapping the threats and building the capacity to manage them". The project is currently working on a number of areas including production of a map (GIS mapping and data retrieval) to produce a strategic overview of where disease has expressed in the region based on aerial photos, and isolation data from Vegetation Health Service database. SCRIPT, in partnership with the Forest Management Branch of the Department of Conservation and Land Management, is collating data and information to assist in their evaluation. The project is considering evaluating disease risk based on a range of criteria (e.g. soils, susceptibility of vegetation, distance of assets from known infections, vectors in area). Emphasis will be placed on the large disease-free areas of high value.

At a larger scale, a risk analysis of the current and potential distribution of *P. cinnamomi* in Victorian National Parks was undertaken by Gibson *et al*. (2002). A database of occurrence records, susceptible species and climate and topography GIS layers were used to develop predictive maps of potential future occurrence and of risk of introduction of the disease. The five-minute grid map covering Victoria was generated using State Flora Information System site records as a basis. The analysis utilised elevation, annual rainfall, the density of roads and tracks and the average number of susceptible species per quadrat.

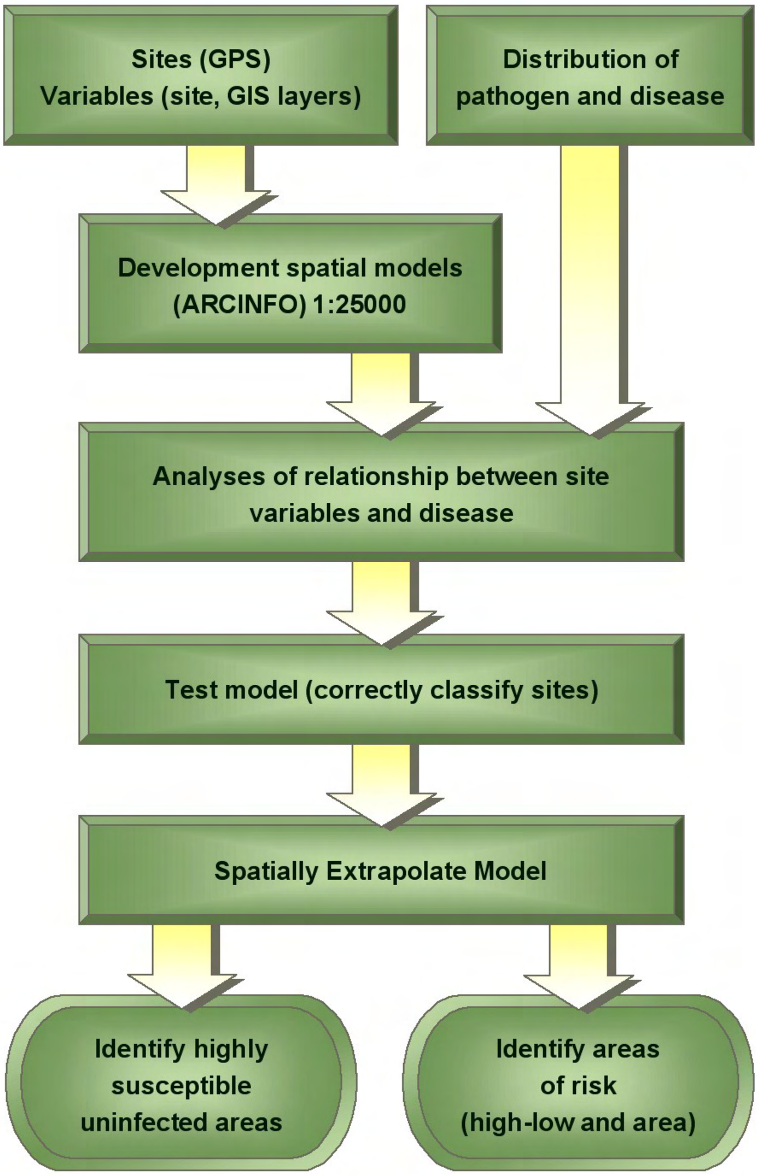

Figure 4.3 Development of predictive GIS spatial model of distribution of *Phytophthora cinnamomi* infection in the eastern Otways Victoria (Wilson *et al.*, 2003).

The risk analysis involved four stages:

1. The potential range of the pathogen was defined following assessment of the distribution of positive *P. cinnamomi* sites (database) and information regarding annual rainfall and elevation limits.

2. Assessment of the occurrence of susceptible species and densities of roads and tracks were each classified into three classes and then combined using a matrix to give high, medium, low and unknown risk classes.

3. Risk classes were overlayed on Parks (National Parks Act, 1975) to assess the distribution of risk classes within each Park.

4. The results of the risk classification were related to datasets including the distribution of rare and threatened flora and fauna.

Assessment of climatic and topographic parameters found that conditions are suitable for *P. cinnamomi* to potentially occur over 60% of Victoria. *P. cinnamomi* occurs in over 30% of the 85 parks listed under the National Parks Act, 1975. In over half of the studied parks 8 to 12% of recorded species are susceptible and 58% of all grid cells had an average of up to 10 susceptible species. Parks and regions that support heathland and heathy woodlands contained high numbers of susceptible species. Of the total area of parks in Victoria approximately 12 205km^2 (40%) was assessed as climatically and topographically suitable for disease and one third of this area is of high risk.

4.6.1 Criteria for risk mapping models

The reviews of risk mapping currently being employed both in Australia and elsewhere provided the basis for selecting those models or aspects of models that may be suitable in order to develop models for risk assessment for *P. cinnamomi* in Australian ecosystems. A number of criteria were chosen to assess their suitability including:

- Applicability/Useability
  - is the risk mapping related to the biology of the pathogen and does it include suitable predictive attributes e.g. climate, susceptible vegetation and topography
  - is the mapping suitable for mapping at different scales and localities
  - is the mapping useful for predicting future distribution
  - is the model easy to implement
  - is the technique available to different organisations?
- Outputs
  - are they are useful, and to whom e.g. catchments, national parks, regions, local parks and DEH/Land Managers
  - are recommendations prioritised?
- Costs
  - the cost of the system e.g. GIS, mapping including available expertise, systems and data.
- Stakeholder participation
  - can stakeholders participate?

4.6.2 Summary of the best models and features for risk mapping in Australian native ecosystems

The methods that were assessed were developed for different purposes and at different scales (Table 4.4). All were GIS based and thus the methodology was applicable to risk mapping for *P. cinnamomi*. Several were models designed for *P. cinnamomi* so were directly related to the biology of the pathogen (Gibson *et al.,* 2002, Wilson *et al*., 2003; SCRIPT, 2004). Others were related to the biology of other pests and pathogens which are not soil-borne including *P. ramorum* which is airborne (Shaw and Britton, 2003). The preliminary risk map developed in 2003 in the United States for *P. ramorum* was based on potential introductions, susceptible plant species, weather conditions favourable to *P. ramorum* survival and disease development. The model is thus similar in methodology to those reviewed for *P. cinnamomi* and employs predictive attributes suitable for the pathogen.

Table 4.4 Criteria and assessment of risk mapping models.

Criteria	Comments				
Models	Mapping risk from insects and diseases in forests	Sudden Oak Death National Strategic Plan	*P. cinnamomi* in Parks and reserves across Victoria	A spatial model for predicting *P. cinnamomi* in south-eastern Australia	*P. cinnamomi* in regional south-western Australia
Useability	Not directly related to biology of *P.cinnamomi* at a national & state level	Not directly related to biology of *P. cinnamomi* at a national & state level	Related to biology of pathogen. Applicable at a state level	Related to biology of pathogen. Applicable at regional and local levels	Related to biology of pathogen. Applicable at regional and local levels
Outputs	Maps and priorities for DEH and land managers	Maps and priorities for DEH and land managers	Maps and priorities for DEH and land managers	Maps and priorities for DEH and land managers	Maps and priorities for DEH and land managers
Costs	Costly	Costly	Reasonable costs and time frame	Reasonable costs and time frame	Reasonable costs and time frame
Stakeholder participation	Government departments	Government departments	Government departments	Government departments & researchers	Govt. depts., researchers & community stakeholders
Reference	Lewis (2002)	Shaw and Britton (2003)	Gibson *et al.* (2002)	Wilson *et al.* (2003)	SCRIPT (2004)

The risk mapping models were all at different scales. A number were at the continental scale (Lewis, 2002; Shaw and Britton, 2003). The continental scale "Mapping Risk from Forests Insects and Diseases" (Lewis, 2002) was developed by regional staff throughout the United States used empirical data, models and expert judgement. The data were compiled from various sources and subjected to updates. The results were not intended for site-specific analysis but the results enabled national emphasis to be focused on those areas where effective treatments are available. The project also produced results to assist land managers to reduce risk in the areas identified on the map, while keeping other areas healthy. These results supported a national priority for Forest Health Protection and provided a basis for prioritisation. The results identified what land tenure was most at risk and what taxa groups accounted for most of the risk. The project recognised that the risk map is only one of several layers of information needed to provide a national representation of forest health. Other national maps (fire, wildland/urban, and threatened and endangered species) are under development.

Other models were at regional/catchment scales (Wilson *et al*., 2003; SCRIPT, 2004) and others at the state scale (Gibson *et al*., 2002; Table 4.4). The state level model covering Victoria was generated using State Flora Information System site records as a basis and utilised elevation, annual rainfall, the density of roads and tracks and the average number of susceptible species per quadrat (Gibson *et al*., 2002). The methodology had limitations including; the incomplete database of *P. cinnamomi* sites, the limited understanding of species susceptible to *P. cinnamomi* and the level of susceptibility and the limited choice of variables due to lack of availability of state-wide datasets. In addition, there were concerns regarding the methods used to classify variables (e.g. cut-off points for classes) were arbitrary and can impact on results. The risk classes of high, medium and low only have meaning relative to each other. Further, there was concern that the correlation between road density and disturbance is assumed and not quantified.

Alternative models using different spatial resolution, different variables, and methods to classify and combine variables are possible. For example, a risk index could be developed based on adding or multiplying variables. Indeed this model was recently further refined by the addition of suitable soils data. This is a very useful model for *P. cinnamomi* risk mapping at this scale. Issues of databases need to be addressed and there is a need to improve the predictability of the model by addressing the concerns and testing more quantitative methods.

The catchment scale model (Wilson *et al*., 2003; Table 4.4) utilises quantitative modelling techniques, with statistical analytical tools, improving the predictability. The logistic regression model was spatially extrapolated and predicted that up to 74% of the study area had a high probability of being affected by *P. cinnamomi*. However, the present areas of infection were small, providing an opportunity for management to minimise spread of disease into highly susceptible uninvaded areas. The analysis undertaken was based on static data obtained at the time of sampling, whereas the spread of the pathogen is dynamic. The model is important, however, in locating highly susceptible uninvaded sites that need to be managed to minimise extension of disease from areas infected currently. Further, it does provide the basis for the future development of dynamic models of *P. cinnamomi* infestation which is discussed further in Section 6.

4.7 An overview of existing risk assessment models

A range of models of risk assessment that may be applicable for *P. cinnamomi* in Australian ecosystems have been developed. They include qualitative, semi-quantitative and quantitative models. A number of models are considered here, some have been applied to pest animals and plant pathogens and others to stressors such as salinity.

A risk assessment for the import and keeping of exotic vertebrates in Australia was developed by the Bureau of Rural Sciences, Canberra (Bomford, 1993). The model was developed for the Vertebrate Pest Committee (VPC) to place exotic vertebrate species into threat categories which can be used for setting appropriate import and keeping restrictions for Australia. The risk assessment was based on the potential for a species to establish in the wild, the failure to eradicate the species and for it to become a pest. Three risk scores were calculated: a) danger posed by individual animals e.g. risk that escaped individuals will harm people; b) establishment likelihood e.g. the risk that a species will establish a wild population in Australia, and c) establishment consequence e.g. the risk that an established population of a species will cause harm (i.e. become a pest).

Climate match modelling CLIMATE software (Pheloung, 1996) was employed to determine if a pest species climate range was suitable in Australia, compared to their known climate range overseas. Studies have shown that good climate matches are significantly correlated with the current geographic range of established vertebrate pests (Duncan *et al*., 2001). Scores were then used to determine the species VPC Threat Category: extreme, serious, moderate or low.

Hart *et al*. (2003) assessed the ecological risk to aquatic catchments systems from increasing salinity. They developed a conceptual model of the relationships among the system components in a freshwater catchment and undertook a risk assessment of the increase in salinity on wetlands and rivers of the Goulburn-Broken catchment system in Victoria. The risk assessment involved quantitative estimations of the probability of exceeding the salinity tolerance for proportions of the taxa, an expectation of the effect on biodiversity over given time periods, and the expected loss of 'flagship' species (e.g. Murray cod). Salinity distribution curves (likelihood) for rivers and wetlands were obtained from monitoring data, or from a hydrological-water quality model. They were applied to models to predict distributions of likely future salinity values. The sensitivity of aquatic species to salinity was estimated as maximum salinity values (EC_{max}) at which the taxon has been recorded in the system under consideration. Estimates of the proportion of species likely to be subjected to intolerable salinity levels (consequence) based on the predicted salinity concentration distribution were undertaken.

A number of risk assessment models are available for *Phytophthora* pathogens. *Phytophthora lateralis*, a soilborne pathogen, is a significant risk to Port Orford Cedar forests of the United States. An assessment of the distribution of Port Orford Cedar, its economic and social values and the impacts of *P. lateralis* was undertaken (Betlejewski *et al*., 2003). A risk assessment to determine possible strategies for attaining the long term goal of maintaining the ecological presence and economic viability of Port Orford Cedar was also completed and management techniques were developed. The risk assessment was qualitative and based on identification of possible strategies (no action, slow the rate, stop the spread or exterminate *P. lateralis*). The assessment identified four key elements (value, hazard, exposure and susceptibility) and assessed which element has the potential for management. Exposure was identified as having current opportunities for management. Factors correlated with exposure to infection were subjectively rated as high, medium or low, on their importance to risk (Table 4.5). Factors were also assigned a value of 3, 2 or 1, based on the ability to manage or control them. Total scores for risk and control values were calculated and used to rank the risk factors in this case total scores ranged from 2 to 6.

Table 4.5 Factors affecting risk of infection of Port-Orford cedar by *Phytophthora lateralis* (after Betlejewski *et al*., 2003). Quantitative values are assigned to risk and control: L = 1, M = 2, H = 3. Rank is calculated as the sum of risk and control.

Influencing Factor		Risk	Control	Rank
Physical factors	Geologic rock type	L	L	2
Average rank = 2.7	Elevation	L	L	2
	Aspect	L	L	2
	Slope steepness	M	L	3
	Slope position microtopography	M	L	3
	Slope position macrotopography	M	L	3
	Soil moisture	M	L	3
	Drainage density	M	L	3
	Proximity to stream, water or flood plains	H	M	5
	Annual rainfall	L	L	2
	Average annual temperature	L	L	2
Biological factors	Plant association	H	L	4
Average rank = 4.5	Port-Orford-cedar density,extent, juxtaposition	M	H	5
	Density or cover of other hosts	M	H	5
	Adjacent infection	H	H	6
	Adjacent infection of cultivars	H	L	4
	Recent dead (density and proximity)	H	H	6
	Seral stage	L	H	4
	Animal populations as vectors	L	L	2
Roads and road related vectors	Road density	H	M	5
Average rank = 4.8	Road surface	H	H	6
	Proximity to road	H	M	5
	Other road design factors (usually drainage)	M	M	4
	Culverts	H	H	6
	Ditches	H	H	6
	Traffic density	H	M	5
	Traffic type	M	H	5
	Right-of-way agreements	M	L	3
	Off-road vehicle traffic	H	M	5
	Trails (same as roads)	M	H	5
	Fishing traffic	L	L	2
Harvest/extraction	Harvest frequency	M	H	5
Average rank = 5.3	Harvest method	H	H	6
	Bough harvest	H	H	6
	Mining	H	L	4
Opportunity to control exposure	Ownership pattern	M	L	3
Average rank = 3.0	Land allocation	L	M	3

To delineate areas of different risk it was proposed to apply the total risk values to areas which can be mapped using GIS. The maps can then be used to make decisions of whether or not to mitigate the risk and what methods to employ (Betlejewski *et al*., 2003). The cost of treatment and the social acceptance of such treatments were some additional factors requiring consideration before implementation.

Emergency measures were implemented in September 2002, when the presence of *P. ramorum* was recognised in Europe, to prevent the spread of European isolates and introduction of non-European isolates in Europe (Baker *et al*., 2004). A three year project funded by the European Union focussed on assessing the risks posed by the pathogen to European trees and significant habitats. These included woodlands, heathlands, Mediterranean maquis and other southern evergreen forests. The risk analysis will assess the potential for establishment of the pathogen, environmental and socio-economic impacts, and develop risk management strategies and contingency plans. Although the assessment will utilise data and information that is already available a major part of the project is research to provide data (RAPRA website - Risk analysis for *Phytophthora ramorum*, accessed 2/9/05).

Risk assessments of *P. ramorum* have been completed in Canada, Oregon (USA), The Netherlands, New Zealand and the United Kingdom (Cree, 2003). They have provided the rationale for regulatory programs that have subsequently been implemented. All of Canada is at risk where susceptible hosts of economic, environmental and social values are present (Canadian Food and Inspection Agency and Canadian Forest Service, PRA, 1999). Impacts could include loss of high value trees, reduction of species diversity in unique habitats, and commercial losses due to direct and indirect effects on susceptible oak species. The potential risk to the Netherlands is high and consequences immense if native species are susceptible (Cree, 2003). Predicted impacts on natural ecosystems and landscapes are high. All of New Zealand is at risk from the pathogen with significant hosts such as Douglas fir and redwood (MAF Biosecurity Authority, 2002). The potential impact in New Zealand has not been assessed.

4.7.1 Current processes for risk assessment and setting priorities for *Phytophthora cinnamomi* threats

The current processes for risk assessment and setting priorities for *P. cinnamomi* threats in Australia vary in their level of development and methodology. Possingham *et al*. (2002) employed a decision analysis approach to determine national priority actions for sustaining biodiversity and applied this to evaluating *P. cinnamomi* as a major threatening process. The process outlined the current risk to biodiversity of each major threatening process identified in national objectives and targets for Biodiversity Conservation 2001-2005 (Environment Australia, 2001). This was quantified in terms of the number of native species at risk, as a surrogate for biodiversity because data on genetic diversity or ecosystem diversity are even less available than data on species under threat. The process then calculated biodiversity benefits dependant on the effectiveness of management options, and estimated the financial costs of these options. A cost-benefit analysis was secured for each option, and collateral effects were assessed. These included benefits beyond the biodiversity itself which flowed from management options, for example, erosion control, carbon credits and clean water.

The calculated biodiversity and collateral returns for management options were classified as repair or maintenance, or a mixture of both. They were then further classified into groups according to whether they had high, medium or low values of species secured per $1M, and based on the ratio of collateral benefits to cost. This risk assessment process provided priorities.

The report, Possingham *et al*. (2002), assessed the spread of *P. cinnamomi* as a major threatening process. The decision analysis approach involved quantifying the costs and benefits to prioritise actions for sustaining biodiversity (Possingham *et al*., 2002). The management option of limiting the spread of the pathogen was assessed in the following process:

- Risk was quantified as the number of native species at risk. The total number of species affected was estimated by using a multipling factor (based on the fact that many unrecorded associated species become extinct)
- Biodiversity benefit of the management action was estimated
- Financial cost of the management option was estimated over a 10 year period
- Cost per species secured by management actions was calculated
- Collateral benefits were estimated e.g. erosion control, pollination and honey production.

The calculated biodiversity species benefit of action in limiting the spread of *P. cinnamomi* as determined by Possingham *et al*. (2002) is compared to land clearing (Table 4.6). Possingham *et al*. (2002) took a precautionary approach and included threatened plants that were thought to be susceptible to *P. cinnamomi*. The area seriously affected by *P. cinnamomi* was estimated at approximately 2 million hectares, and the costs of management and research actions $8M annually. The collateral benefits were assessed as savings to agriculture, forestry, plant nurseries, tourism and were estimated at $1 600M. The collateral benefit/total cost was 40 with 35 species secured per $1M. In comparison to other risks to biodiversity the management of *P. cinnamomi* was the highest in terms of collateral benefits per cost (higher than clearing; Table 4.6, and biological weeds; 16 species saved/$1M; collateral benefit/total cost 10) and amongst the highest for species secured.

Table 4.6 Cost benefit analysis on biodiversity of limiting the spread of *Phytophthora cinnamomi* compared to clearing in Australia (Possingham *et al*., 2002).

Factor	**Limiting spread of *P. cinnamomi***	**Prevent broad scale clearing of communities of high biodiversity value in Queensland**
Number of species saved	1,400	5,280
Area (hectare)	2,000,000	2,270,400
Cost ($/hectare)	20	88
Total cost ($ million)	40	200
Nos species saved/$ million	**35**	**26**
Collateral benefit ($ million)	1,600	4,008
Collateral benefit/total cost	**40**	**20**

At the state level there have been different approaches to risk assessment. In Western Australia, a risk assessment procedure "*Phytophthora cinnamomi* Risk Assessment" is currently in draft (CALM, 2004). This guide, for planning and management teams, provides risk management procedures that involve identifying, analysing, evaluating, managing, monitoring and communicating about risks, and is based upon AS/NZS 4360 (1999).

The SCRIPT (South Coast Regional Initiative Planning Team) project in the south west Western Australia aims to establish a methodology for the development of threat assessment at a landscape scale. The project, funded by the National Heritage Trust, has three major components: compiling information on disease occurrence and impact, the production of risk assessment maps and community involvement. The project was begun in 2004 and aims to establish a methodology for the development of landscape scale threat asessment maps relevant for all Western Australian bioregions and of assistance to managers in other states. SCRIPT in partnership with the Forest Management Branch of the Department of Conservation and Land Management is collating data and information to assist in the risk assessment. A major emphasis of the risk assessment process is on identifying and evaluating areas that are still free of disease. The term "Dieback Priority Protection Areas" was selected as an appropriate term for areas identified as being high priority for dieback risk assessment at the operational scale.

The project is considering evaluating disease risk based on a range of criteria (e.g. soils, susceptibility of vegetation, distance of assets from known infections and the presence of vectors) and determining assets and values that require protection from disease (e.g. biodiversity hot spots, endemism, threatened species and communities, sites of cultural significance, water quality, landscape/ tourism, honey production and floriculture).

In South Australia, information on the effect of *P. cinnamomi* on threatened plant species is very limited. A draft risk assessment for specific areas that are a high conservation priority is currently being prepared (Velzeboer *et al*., 2005). The aim is to prioritise 20-25 threatened plant species that might be threatened by *Phytophthora* for research (e.g. susceptibility, phosphite treatment and mycorrhizal fungi studies) and management (protection of species to prevent further decline due to *Phytophthora*). The method involves:

- compilation of a list of threatened plant species (endangered and vulnerable) found in a habitat vulnerable to *Phytophthora*
- determination of the proximity of threatened plant species to a *Phytophthora* infestation based on four categories High Risk Management Zone, Moderate Risk Management Zone, Low Risk Management Zone and Low Risk Area
- scoring of Threatened plant species based on species status (S), proximity to *Phytophthora* infestation (P) and a total score calculated (S × P)
- Listing of Threatened plant species in priority order with the highest priority at the top and lowest priority at the bottom according to the total scores.

In Victoria, the extent to which risk ratings have been applied is limited (Gibson *et al*., 2002). General guidelines for the control of *Phytophthora* dieback in Parks are provided in Niewand *et al*. (1995). These guidelines suggest that each Park is broadly classified as potentially susceptible or not, based on the presence of susceptible plant communities, that disease risk ratings are applied and that protectable areas are identified. The general guidelines by Niewand *et al*. (1995) also detail protocols for the identification of infested areas within high risk areas. The "Draft Strategic Plan for Management of *Phytophthora cinnamomi* in Victoria" (Department of Sustainability and Environment, 2004) has identified the requirement to develop a state wide risk assessment of the threat across all land management agencies for the purpose of prioritising areas. The risk analysis of the current and potential distribution of *P. cinnamomi* in Victorian National Parks undertaken by Gibson *et al*. (2002) provides a basis for developing a state wide risk assessment and prioritisation.

In Tasmania, a risk assessment approach for managing the effects of *P. cinnamomi* involved selection and prioritisation of management areas for the purpose of safeguarding susceptible rare and threatened plant species at greatest risk (Barker *et al*., 1996). The selection was based on maintenance of biodiversity and identification of the smallest number of sites needed to achieve the aim (Barker *et al*., 1996). The basis for selection of areas was the minimisation of the risk of introducing the pathogen into defined areas. The process involved:

- selection of taxa based on susceptible native rare or threatened plant species and Tasmanian endemic species
- delineation of potential management areas
- prioritisation of areas based on criteria (diversity, conservation status or *P. cinnamomi* manageability)
- selection of the best three management areas for each species.

Of the 101 Tasmanian areas surveyed, 74 were selected based on their biodiversity and with the aim of selecting triplicate sites where possible. Thirteen of these were rejected on manageability criteria. The remaining 61 were selected for management and contained all 44 target species.

Subsequent to the procedure developed by Barker *et al*. (1996) a report into the establishment of a number of Phytophthora Management Areas (PMA) in Tasmania is in preparation (Schahinger *et al*., 2003). Phytophthora Management Areas have been identified to identify representative areas that are least at risk of the introduction of *P. cinnamomi* and contain a population of one or more susceptible threatened species (with up to 3 populations/species) and/or a highly susceptible plant community. The PMA may be infested, where the management objective is to minimise spread and impact, or uninfested and subject to strict management prescriptions to control high risk activities. Two categories of uninfested areas were defined as those with: i) unrestricted access, where the threat of introducing *P. cinnamomi* is considered manageable for high risk activities or, ii) limited access, where the threat of introducing *P. cinnamomi* is considered manageable for all activities.

4.7.2 Criteria for risk assessment models

The reviews of risk assessment currently being employed both in Australia and elsewhere provided the basis for selecting those models or aspects of models that may be suitable in order to develop models for risk assessment from *P. cinnamomi* in Australian ecosystems. The criteria selected for risk assessment methods included:

- Applicability
  - whether the risk assessment process is related to the biology of the pathogen and includes attributes of climate and susceptible vegetation
  - whether the risk assessment is suitable for assessment of risk from *P. cinnamomi* to species, communities, biodiversity and ecosystems at different scales and localities.
- Outputs
  - whether they are useful, and to whom e.g. catchments, national parks, regions, local parks and DEH/Land Managers.
- Availability
  - whether the technique is available to different organisations.

- Costs
  - the cost of the system including available expertise, systems, data etc.
- Stakeholder participation
  - can stakeholders participate effectively?

4.7.3 Summary of the best models and features for risk assessment in Australian native ecosystems

The Australian Standard for Risk Management (AS/NZS 4360: 1999) defines the elements of good procedures for risk assessment in Australia. The processes and steps outlined in the standard are excellent and, in general, can be included or used as guidelines for the model for *P. cinnamomi*. However, other relevant criteria are required that are specific for the risk of this soil borne pathogen. In particular, the models must encompass the high levels of uncertainty about the pathogen, its methods of infestation and movement, and effects on communities, flora and fauna.

The risk assessment models considered were developed for different purposes, at different scales and none were full risk assessments as defined by The Australian Standard for Risk Management. Most of the models addressed aspects of the standard such as establishing the context, identifying the risks (hazards/threats) of *P. cinnamomi* and analysing the risks. Few models addressed evaluation and prioritisation of risks, treatment or management of risks, or the identification of a range of options as to whether to take actions (e.g. accept the risk and do nothing, reduce the likelihood, or reduce the consequences). Monitoring and review procedures were not addressed and most did not incorporate costs or cost-benefit analyses. Few models reported effective communication of risk assessment to the stakeholders. This is seen as an important process to ensure that those people with responsibilities understand the basis on which decisions are made.

Description of seven of the most suitable models

Risk assessment for the import and keeping of exotic vertebrates in Australia

The risk assessment for the import and keeping of exotic vertebrates in Australia (Bomford, 1993; Table 4.7) was developed to determine a species' Threat Category. The model employed a semi-quantitative method based on a scoring system of the danger posed by animals e.g. risk that escaped individuals will harm people; the likelihood that a species will establish a wild population in Australia, and the consequence-risk that an established population of a species will cause harm (i.e. become a pest). Climate match modelling was employed to determine if a pest species climate range was suitable in Australia, compared to their known climate range overseas. Limitations of this model include uncertainty in the data set and knowledge. For example, there is no assessment of introduction effort (the number of times the species is introduced) in the risk assessment. There are limitations to using the climate matching for predicting potential range in Australia because a species' actual range overseas may be smaller that its potential range. Stochastic events may have a major influence on whether a given release event leads to a species becoming established and subsequently a pest. Also the scientific knowledge in this area is not well established. Further, the risk assessment was based on data from past successful introductions of mammals and birds in Australia and the model was not tested on independent data.

Risk assessment model of the ecological risk to aquatic catchments systems from increasing salinity

The risk assessment model of Hart *et al*. (2003) which assessed the ecological risk to aquatic catchments systems from salinity increases involved quantitative estimations of the probability of exceeding salinity tolerances for proportions of the taxa, and the effects on biodiversity (Table 4.7). A number of aspects of the model which may affect outcomes were discussed. These included the selection of threshold concentration from species distribution data, the decision or judgement on how often the threshold may be exceeded before significant effects on ecosystems will occur, and the consideration that there is no assessment of the resilience of the species to salinity increase. The study highlighted the challenges and problems associated with current ecological risk assessment methods, particularly how to better quantify the linkages between stressors and the biota, and how to better handle uncertainties.

Table 4.7 Criteria and summary of risk assessment models.

Criteria	**Comments**					
Models	Risk assessment for the import and keeping of exotic vertebrates in Australia	Ecological risk to aquatic catchments systems from salinity increases	Risk assessment for impact of *P. lateralis*	*P. ramorum* models	Setting biodiversity priorities	Design of *P. cinnamomi* management areas for threatened flora in Tasmania
Useability	Adaptable to biology of pathogen. Applicable at national and state levels	Not related to biology of pathogen, good modelling - adaptable to pathogen. Applicable at state and local levels	Adaptable to biology of pathogen Applicable at national and state levels	Adaptable to biology of pathogen. Applicable national and state levels	Adaptable to biology of pathogen. Applicable at national and state levels	Related to biology of pathogen. Applicable at state and local levels
Outputs	Priorities for DEH and land managers	Quantitative assessment of impacts on biodiversity	Ranking risk factors	Maps, priorities	Priorities	Priorities for DEH and land managers
Costs	Costs/time reasonable	Reasonable	Costs/time reasonable	Costly	Costs/time reasonable	Costs/time reasonable
Stakeholder participation	Govt depts.	Govt depts. and research	Govt depts. and research	Govt depts. and research	Govt depts. and research	Govt depts. and research
Reference	Bomford (1993)	Hart *et al.* (2003)	Betlejewski *et al.* (2003)	Cree (2003)	Possingham *et al.* (2002)	Barker *et al.* (1996)

Risk assessment - identification of hazards of taxa from ballast water into marine systems

The model of Hayes (2002a) assessed the hazard of bio-invasion of exotic taxa from vessel ballast water into marine systems (Figure 4.2). It involved utilisation of a hazard-analysis tool, 'Fault Tree analysis' to identify parallel and sequential events that lead to successful infection at a port. The model highlighted the complexity of the process but identified the roles of ballast tank populations, ballast-water carry-over, crevice seeking taxa, multiple infection scenarios and third-party contamination of donor ports. The model advantages included its emphasis on properties of the organism, and circumstances of introduction; and providing a qualitative model for developing a high quality quantitative model.

The risk assessment for the impacts of Phytophthora lateralis *on Port Orford Cedar*

The risk assessment for the impacts of *P. lateralis* on Port Orford Cedar was qualitative and was also based on a scoring system to determine possible strategies (Betlejewski *et al.*, 2003; Table 4.7). Total scores or risk and management/control values were calculated and used to rank the risk factors. Improvement of the risk assessment model was discussed and it was proposed that quantification of risk factors would be an important progress, making the values more accurate. In this case, a study had found highly significant differences between infested and uninfected sites based on slope position, distance from roads, elevation and distance from the ocean (Jimmerson, 1999). Development of regression models based on multiple variables would provide risk values of greater quantification more precisely than the subjective high- and low-risk estimates in the current model. Cost-benefit analyses were not included.

The model is applicable to *P. cinnamomi* and includes attributes of climate and susceptible vegetation. It provides a basis for a scoring and a ranking system appropriate for risk assessment of the effects of *P. cinnamomi* in native Australian communities. The scoring system could be modified for assessing species, communities and areas. Stakeholders can participate in the scoring and ranking process for prioritisation.

The risk assessment for the impacts of Phytophthora ramorum

The *P. ramorum* risk assessment models are based on the biology of the pathogen (Cree, 2003; Table 4.7). Potential host range, distribution, means of spread, and economic or environmental impacts following introduction are considered to make predictions about the likelihood of introduction and potential impacts in defined areas. The models separately evaluate likelihood and impact before a final assessment or estimate of risk is derived. It has been necessary to revise these risk assessments and subsequently quarantine regulations, as new information on *P. ramorum* has emerged.

The sustaining biodiversity model

The decision analysis approach to determining priority actions for sustaining biodiversity employed by Possingham *et al*. (2002) assessed the spread of *P. cinnamomi* as a major threatening process. It involved quantifying the costs and benefits of particular actions and is seen as a "business-like" way of prioritising actions for sustaining biodiversity (Possingham *et al*., 2002; Table 4.7). It was an excellent example of risk assessment that included:

- quantifying the number of native species at risk (including associated non-susceptible species)
- estimating the biodiversity benefit of management action

- estimating the financial costs of management over a 10 year period
- cost per species secured
- collateral benefits beyond biodiversity e.g. erosion control, pollination and honey production.

This is the most complete risk assessment as it includes identification of the risks (hazards), analysis of the risks including likelihood of occurrence and magnitude of the consequences. In this case, analyses were qualitative (based on the best estimate and/or expert opinion). Cost benefit analyses are included in this model, in particular the cost of inaction. The main strength of this method is that it addresses biodiversity and collateral values and is not limited to species or communities. A further strength of this model is that figures and costs employed in the risk assessment were sourced mainly from nationally audited data and reports. The method could be developed to evaluate and prioritise risks across Australia and to identify a range of options as to whether to take actions for example to accept the risk and do nothing, or to reduce the likelihood, or reduce the consequences).

Design of **Phytophthora cinnamomi** *management areas for conservation of threatened flora in Tasmania*

The Tasmanian model designed by Barker *et al*. (1996) has a number of strengths (Table 4.7). It is based on the need to prioritise management consistent with the level of risk and manageability. The approach is to prioritise areas for management so as to obtain the highest cost-benefit. The criteria used to rank do include an estimation of conservation/diversity status (number of target species).

5 RECOMMENDATIONS AND CONCLUSIONS

Two model types are recommended (Figure 5.1). The first is a macro-scale model which is part of a process to show where risks are at the landscape or catchment level (Hart *et al*., 2003). Mapping of the distribution of *P. cinnamomi* and the likelihood of infestation is required to determine where the risks are at the landscape and catchment levels. The second risk assessment model involves the analysis of likelihood and consequence of infection for species, communities and areas or localities. This model can also include aspects of manageability and cost-benefit analysis.

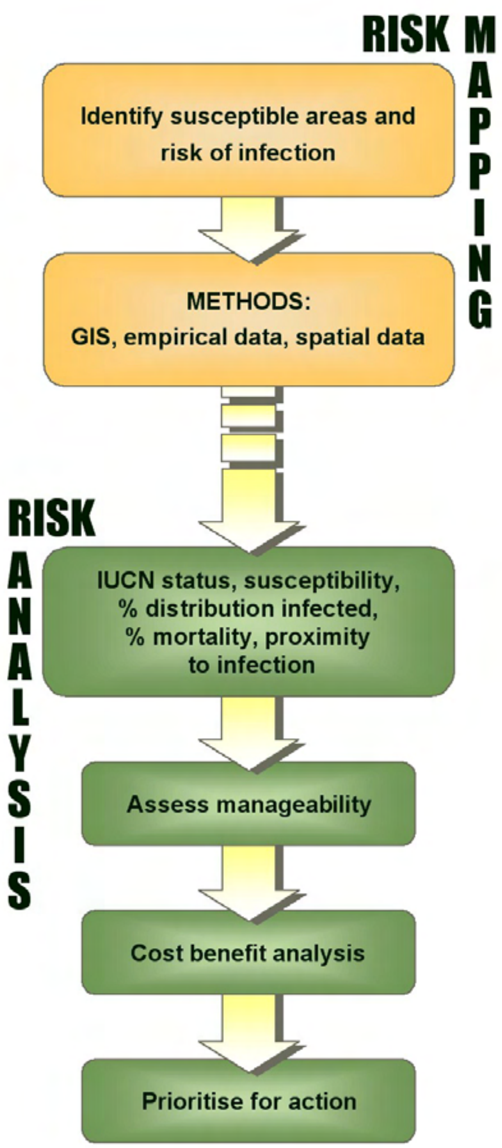

Figure 5.1 An overview of risk assessment and risk mapping components.

5.1 Mapping and spatial models

All the GIS based methodologies are applicable to risk mapping for *P. cinnamomi*. They provide the following:

- identification of healthy areas and focus on areas where effective treatments are available
- identification of taxa and communities at risk
- assistance to land managers to reduce risk in identified areas while keeping other areas healthy
- a basis for prioritisation
- identification of which land tenure is most at risk.

Issues involved with lack of adequate data bases need to be addressed. There were few models that employed quantitative modelling techniques combined with spatial modelling. We need to improve the predictability of the model by addressing the concerns and testing more quantitative methods. This would be important also for improving our capabilities with regard to future possible incursions of other pathogens.

5.2 Risk assessment and prioritisation for species, communities and localities model

Based on the assessment of current risk assessment models available, the availability of quantitative data, and the criteria developed, three models were tested and are recommended for prioritisation of species, communities and areas (Part 4: Risk Assessment Models for Species, Ecological Communities and Areas). These models were selected based on the objectives identified in the tender: *to develop risk assessment criteria and processes that can be adopted nationally as a standard to determine the level of threat that* P. cinnamomi *poses to a species, communities and areas*. Due to the limitations of appropriate quantitative modelling a scoring approach to risk assessment is employed in these models and therefore produces indicative assessments. These are the best that can be achieved based on current scientific knowledge and expert judgements. This means that assessments are subjective, and this will affect the risk scores. The models involve judgements on the relative significance of factors, so are influenced by subjectivity which will affect the model outputs.

As our understanding of the factors affecting the pathogen improves, the quantification of risk for the factors will be more accurate. Development of statistical methods and models (e.g. multiple regression analyses, spatial and epidemiological models) showing relationships between variables and the pathogen will result in more precise values. The proposed models are viewed as part of an iterative process with modifications made to scoring, as more accurate values and probabilities are known.

The models produce Risk Categories that can be used to rank species, communities and areas based on the likelihood of *P. cinnamomi* infestation, the consequences or effects and manageability of the disease. They do not include estimates of management costs (e.g. planning, implementation and monitoring), or cost-benefit analysis of different management approaches. This information may be required by managers for informed decision making and is addressed elsewhere (Part 4: Risk Assessment Models for Species, Ecological Communities and Areas).

Implementation of the models should address aspects such as establishing the context, monitoring and review procedures, and effective communication of risk assessment to the stakeholders so as to ensure those with responsibilities understand the basis on which decisions are made.

5.3 Procedures followed for developing risk ranking models (after Burgman, 2005)

The procedures employed in this project for developing the risk ranking models are summarised in Table 5.1. Much of the revision and iterations of the models were undertaken between meetings. A number of iterations resulted in the models that we have tested and recommended (Part 4: Risk Assessment Models for Species, Ecological Communities and Areas).

The process recommended (Table 4.1) has been followed substantially, however, some areas have not been fully developed, for example, there was no training for estimating probability or differences in ranking hazards and risks.

Table 5.1 Method used for risk ranking for species, communities and areas.

Stage	Actions
Context and background	Review of background information, identify experts, stakeholders. Develop working models, guidelines-send to participants.
Meeting 1 June 2004	**Summaries** - State -RA&Ps* - not well developed. **Risk assessment criteria and processes -** A system of prioritisation taking into account assets, activity (likelihood of spread), susceptible fauna and flora species, topography, climate and consequences.
Meeting 2 Sept 2004	Revisited 'Statement of Requirement' for RA&P. Discussed document plan. Reviewed tables of current RA&P systems in Australia and databases. Prioritisation of species/communities may include criteria: status (IUCN, listings) – consequence, proximity to infestation-likelihood, refugia, % distribution of species already infected, % mortality, fecundity-likelihood.
Meeting 3 Dec 2004	Feedback from PRG*on tables in the draft document: conservation status-consider separately, for threatened/susceptible/critically endangered species, ex-situ conservation needs to be considered; keep consequences separate from likelihood. Draft models sent to land managers, feedback obtained.
Meeting 4 Mar 2005	Risk assessment models-revisited: audience - DEH, land managers; keep species, communities and areas separate; keep risk and manageability scores separate; simplify models, condense variables; discussed weightings for variables. Draft models –further testing and refining by state PRG representatives.
Meeting 5 August 2005	Final PRG workshop of models with data from states.

*RA&P (Risk Assessment and Prioritisation); * PRG (Project Reference Group)

6 GAPS IN KNOWLEDGE AND FUTURE RESEARCH

Risk assessment is an ongoing process and as information changes so does the conclusion of the assessment. This has presented a significant challenge for risk assessors who must make judgements even when information is incomplete. The models we have recommended for risk mapping and risk assessment are based on the current state of knowledge of the pathogen and its effects, and of risk assessment processes and methods. We have determined areas where there are significant gaps in knowledge, and identified requirements for research that may address these and lead to improvements in risk assessment for *P. cinnamomi* and other similar plant pathogens in the future.

6.1 Databases and information for *Phytophthora* dieback available across Australia

The databases and information needed to develop risk assessment processes were reviewed on a state by state basis. Limitations to available databases were identified including; incomplete databases of *P. cinnamomi* records; few accredited laboratories for diagnostic services for isolation of *P. cinnamomi;* inadequate state flora data records and systems; lack of information and understanding of susceptibility of plant and fauna species, especially rare and threatened taxa and communities. In addition, the lack of long-term monitoring of dieback affected sites for patterns of infestation intensity, rates of spread, recovery and survival of plants and animals means that the epidemiology of *P. cinnamomi* is poorly understood. Limited choice of predictor variables due to lack of availability of state-wide datasets or data at incompatible scales were also identified as an impediment to risk mapping and modelling.

Research and development priority areas were identified as:

- develop central state-wide databases of *P. cinnamomi* records
- develop and identify accredited diagnostic laboratories
- determine the susceptibility of taxa to *P. cinnamomi*
- identify genetic resistance in populations of susceptible rare/endangered flora
- develop state databases for recording susceptible taxa and communities
- establish long-term monitoring of dieback affected sites
- develop spatial databases of predictor variables, such as soils.

6.2 Impacts of *Phytophthora cinnamomi* on communities and ecosystem function

The focus in ecological risk assessment has shifted to ecosystems rather than concentrating on single species. We need to have a much better understanding of what is at risk in the ecosystems and communities under threat from *P. cinnamomi*. There is a need to assess the effects, and to develop suitable measurements and indices. These include assessments of attributes including biodiversity, ecosystem condition and ecosystem services. There is also little understanding of the resistance and resilience of communities to *P. cinnamomi,* and the capacity for restoration.

Research priority areas were identified as:

- determine the relationship of inoculum levels and disease development in different plant communities
- investigate the impacts on fauna populations, communities and habitats
- investigate the impacts on food availability (nectar, pollen, fungi or invertebrates)
- investigate the impacts on biodiversity
- determine the effects on ecosystem services (hydrological and nutrient cycles, soil fertility)
- determine appropriate measures or indices for assessing the effects on biodiversity, ecosystem condition and ecosystem services
- determine the long term ecological impacts of dieback disease, and the resilience of different communities and ecosystems.

6.3 Risk mapping in Australian native ecosystems

Spatial models based on GIS have been used with success to develop predictive models for *P. cinnamomi* distribution and to produce digital maps of occurrence. The models are limited however due to lack of availability of datasets such as soils and species distribution.

Quantitative modelling techniques, with statistical analytical tools, have been developed for predicting risk of infestation however we need to improve the predictability of the models by testing different models and quantitative methods. The analyses so far have been based on static data, whereas the spread of the pathogen is dynamic. There is a need to develop dynamic models of *P. cinnamomi* infestation. Knowledge of the patterns and rates of extension of the disease are important for developing dynamic models. Rates of extension vary (up-, down- and across-slope), and between different communities and ecosystems (Strelein *et al*., 2005). Long-term monitoring sites are required to improve knowledge.

There have been a number of recent developments in the application of remote sensing to the analysis of forest health and of vegetation structure (Coops and Catling, 1997; Stone *et al.,* 2000). For example, high resolution videography obtained using low flying aircraft that utilise multispectral imaging can resolve features on the ground less than 1m in size (Coops and Catling, 1997). Remote sensing techniques may prove useful for mapping and monitoring *P. cinnamomi* infestations over a broad scale. In Western Australia, remote sensing has been investigated for assessing Dieback (Behn, 1985; Behn and Campbell, 1992). Recently, videography, at 2m resolution, and digital image analysis have been used to examine and map the distribution of *P. cinnamomi* in heathlands at Anglesea, Victoria (Hill *et al.,* 2005).

Other dynamic models should be investigated for their applicability for risk mapping for *P. cinnamomi* in Australian native ecosystems. These could include linked disease crop models that have been developed to assess the quantitative effect of disease on crop growth (Sutherst *et al*., 1996; Teng *et al*., 1996). The models link pathogen (number and severity) and crop variables (e.g. leaf area and photosynthetic rate) (Luo *et al*., 1995). Models developed by the Australian Bureau of Agricultural and Resources Economics to evaluate the effectiveness of management strategies for key pest and disease incursions that pose high level threats to agriculture may also be suitable (Elliston *et al*., 2004a,b).

The extent and nature of climate change will affect the geographical distribution of pathogens, and impact on the host-pathogen interaction (Chakraborty *et al*., 1998). There is a need to assess the effects of future climate change on the distribution of *P. cinnamomi* in Australian native ecosystems, to identify potential areas of distribution and areas of greatest impact. Climate matching algorithms such as CLIMEX (Sutherst and Maywald, 1985; Sutherst *et al*., 1996), and BIOCLIM (Busby, 1991) should be employed to predict likely changes in distribution and areas of greatest severity.

Development of these models would be important also for improving our capabilities with regard to predicting future possible incursions of other similar plant pathogens (e.g. *P*. *ramorum*) into native ecosystems.

Research priority areas were identified as:

- develop quantitative modelling techniques for predicting risk of infestation
- determine and monitor rates of spread of the pathogen
- develop remote sensing and mapping technology for mapping, monitoring and modelling the distribution of *P. cinnamomi*
- investigate the utility of dynamic plant disease models for risk mapping for *P. cinnamomi*
- investigating the effect of seasonal rainfall variation on disease spread and expression
- develop models to predict the effects of climate change on future distribution and impacts of *P. cinnamomi*.

6.4 Risk assessment models

The models selected to develop risk assessment criteria and processes that can be adopted nationally as standard to determine the level of threat that *P*. *cinnamomi* were based on a scoring approach due to the limitations of appropriate quantitative modelling and therefore produces indicative assessments. They are subjective and involve judgements on the relative significance of factors, which affect the model outputs. As our understanding of the factors affecting the pathogen improves the quantification of risk for these factors will be more accurate. Development of statistical methods and models (e.g. multiple regression analyses, spatial and epidemiological models showing relationships between variables and the pathogen will result in more precise values. The proposed models are viewed as part of an iterative process with modifications made to scoring, as more accurate values and probabilities are known.

The decision analysis approach employed by Possingham *et al*. (2002) for assessing the spread of *P*. *cinnamomi* as a major threatening process was identified as an excellent example of risk assessment. Although the analyses were qualitative (based on the best estimate and/or expert opinion) the strength of this method included the ability to determine biodiversity and collateral values, and to employ figures and costs sourced from nationally audited data and reports.

Research priority areas identified were to:

- improve rankings models including training for estimating probability and assessment of sensitivity of rankings
- review models after 12-24 months of use
- develop predictive (expert) systems to quantify disease risk, rate of disease development and level of impact of *P*. *cinnamomi*
- develop models based on the decision analysis approach (Possingham *et al*., 2002) to evaluate and prioritise risks across Australia.

7 REFERENCES

Abell S, Gadek P (2003) Identification and distribution of *Phytophthora* species and genetic population structure of *Phytophthora cinnamomi*. In: 'Rainforest Dieback Mapping and Assessment: *Phytophthora* species diversity and impacts of dieback on rainforest canopies'. (Eds. PA Gadek and S Worboys) Cooperative Research Centre for Tropical Rainforest Ecology and Management. pp1-22 (Rainforest CRC, Cairns).

Ansell J, Wharton F (1992) Risk analysis, assessment and management. (John Wiley & Sons, Ltd., Chichester, England).

Artlab Australia (1999) Development of Best Practice Model for Conservation and Preservation Assessment Planning for Cultural Collections. (Report to Heritage Collection Council) (Artlab Australia, Historical Trust SA, State Library of New South Wales).

AS/NZS 4360 (1999) Risk Management. (Standards Association of Australia, Strathfield, NSW).

AS/NZS 4360 (2004) Risk management. Third Edition. (Standards Association of Australia, Strathfield, NSW).

Australian Heritage Commission (1993) Listing of Anglesea Heath/Bald Hills area, Victoria.

Aven T (2003) Foundations of Risk Analysis. (John Wiley & Sons, Ltd., Chichester, England).

Baker R, Bonants P, Van Den Bogert P, Brasier C, Denman S, Descals E, Elcock S, Goheen E, de Gruyter J, Husson C, Inman A, Kaminski K, Kehlenbeck H, Kessel G, van Leeuwen G, Moralejo E, Sansford C, Shaw CG, Steeghs M, Turner J, Wagner S, Webber J (2004) Risk analysis for *Phytophthora ramorum*-a pathogen threat to Europe (IUFRO Conference, Germany, 2004).

Barker PCJ, Wardlaw TJ, Brown MJ (1996) Selection and design of *Phytophthora* management areas for the conservation of threatened flora in Tasmania. *Biological Conservation* **76**, 187-193.

Barnthouse LW, Suter GW (Eds) (1986) User's manual for ecological risk assessment. (Oak Ridge National Laboratory, Oak Ridge, TN).

Behn GA (1985) An evaluation of the efficiencies of Remote sensing and GIS Technologies for mapping and monitoring Dieback. MSC Thesis, Curtin University of Technology, Perth, Western Australia.

Behn GA, Campbell NA (1992) Dieback assessment using multispectral data over the Stirling Range National Park. WA Department of Conservation and Land Management, CSIRO WA Remote sensing Group.

Belbahri L, Calmin G, Stucker M, Lefort F (2005) Real time PCR for detection of *Phytophthora* species in environmental plant samples. Applied Genetics Laboratory, School of Engineering of Lullier, University of Applied Sciences of Western Switzerland. http://www.hesge.ch/eil/doc/apsh/abstract-real_time.pdf

Beer T, Ziolkowski F (1995) Environmental risk assessment: An Australian perspective. Supervising Scientist Report 102. Office of the Supervising Scientist, Commonwealth of Australia, Canberra.

Beissinger SR, McCullough DR (Eds) (2002) 'Population viability Analysis'. (University Chicago Press, Chicago Illinois, USA).

Betlejewski F, Casavan KC, Dawson A, Goheen DJ, Mastrofini K, Rose DL, White DE (2003) A wide-range assessment of Port-Orford-Cedar (*Chamaecyparis lawsoniana*) on Federal lands. (USFS, BLM and Public Lands, USA).

Bluett V (2001) Distribution of disease caused by *Phytophthora cinnamomi* at Wilson's Promontory National Park, and the response of native plants. Honours thesis, School of Biological and Chemical Sciences, Deakin University. 63 pp.

Bomford M (1993) Risk assessment for the import and keeping of exotic vertebrates in Australia. (Bureau of Rural Sciences, Canberra).

Briggs JD, Leigh JH (1996) Rare or Threatened Plants. Chapter 26 (CSIRO Publishing, Melbourne).

Brown BN (1976) *Phytophthora cinnamomi* associated with patch death in tropical rainforests in Queensland. *Australian Plant Pathology Society Newsletter* **5**, 1-4.

Brown B (1998) Occurrence and impact of *Phytophthora cinnamomi* and other Phytophthora species in rainforests of the Wet Tropics World Heritage Area, and of the Makay region, Qld. In: 'Patch deaths in tropical Queensland rainforests: association and impact of *Phytophthora cinnamomi* and other soil borne pathogens.' (Ed Gadek PA) pp 41-76. Cooperative Research Centre for Tropical Rainforest Ecology and Management, Technical Report, Cairns.

Burbidge AA, McKenzie NL (1989) Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. *Biological Conservation* **50**, 143–198.

Burgman MA (2001) Flaws in subjective assessment of ecological risks and means for correcting them. *Australian Journal of Environmental Management* **8**, 219-226.

Burgman MA (2005) Risk and Decisions for Conservation Environmental Management. (Cambridge University Press, Cambridge, UK).

Burgman MA, Lindenmayer DB (1998) Conservation Biology for the Australian Environment. (Surrey Beatty and Sons, Chipping Norton, New South Wales).

Busby JR (1991) BIOCLIM - a bioclimate analysis and prediction system. *Plant Protection Quarterly* **6**, 8-9.

Cahill DM, Wilson BA, Armistead R (2001a) Dieback assessment at Fairhaven Ridge, Angahook-Lorne State Park, Victoria. Report for Parks Victoria, 32pp.

Cahill DM, Wilson BA, Armistead R (2001b) Assessment of *Phytophthora cinnamomi* at Coalmine Road, Anglesea Alcoa Lease, Victoria. Report for Alcoa Australia, 12pp.

Cahill DM, Wilson BA, Armistead R (2001c) *Phytophthora cinnamomi* Assessment in the Otway National Park. Report for Parks Victoria, 20pp.

Cairns J Jr, Pratt JR (1995) The relationship between ecosystem health and delivery of ecosystem services. In 'Evaluating and monitoring the health of large-scale ecosystems.' NATO ASI Series, Vol.1 28. (Eds DJ Rapport, CL Gaudet, P Calow) (Springer-Verlag: Berlin, in cooperation with NATO Scientific Affairs Division.

CALM (2000) *Phytophthora cinnamomi* and Disease Caused by it. Volume 1 Management Guidelines; Volume 2 Detection, Diagnosis and Mapping Guidelines; Volume 3 Phosphite Operations; Volume 4 Training Curriculum and Syllabi. (Department of Conservation and Land Management, Perth).

CALM (2004) *Phytophthora cinnamomi* risk assessment guide. (Department of Conservation and Land Management, Perth).

Calver MC, Dell J (1998) Conservation status of mammals and birds in south-western Australian forests. I. Is there evidence of direct links between forestry practices and species decline and extinction? *Pacific Conservation Biology* **4**, 296-314.

Canadian Food and Inspection Agency and Canadian Forest Service, PRA (1999) Canadian Food Inspection Agency - Plant Protection - Plant Pest Information - Sudden Oak Death http://www.inspection.gc.ca/english/plaveg/for/pestrava/sodmsce/sodmsce.shtml.

Carpenter SR, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: resilience of what to what? *Ecosystems* **4**, 765-781.

Carey JM, Burgman MA, Chee YE (2004) Risk assessment and the concept of ecosystem condition in park management. Parks Victoria Technical Series No. 13. (Parks Victoria, Melbourne).

Chakraborty S, Murray GM, Magarey PA, Yonow T, O'Brien BJ, Croft BJ, Barbetti MJ, Sivasithamparam K, Old KM, Dudzinski MJ, Sutherst RW, Penrose LJ, Archer C, Emmett RW (1998) Potential impact of climate change on plant diseases of economic significance to Australia. *Australasian Plant Pathology* **27**, 15-35.

Chapman CB (1992) A risk engineering approach to risk management. In: Risk analysis, assessment and management. (Eds Ansell J, Wharton F) (John Wiley & Sons, Ltd., Chichester, England).

Christensen PES (1997) A review of the knowledge of key disturbances in fauna on the south-west forest region. Unpublished Report to the Government of Western Australia for the Regional Forest Agreement.

Colquhoun IJ, Hardy GEStJ (2000) Managing the risks of Phytophthora root and collar rot during bauxite mining in the *Eucalyptus marginata* (jarrah) forest of Western Australia. *Plant Disease* **84**(2), 116-127.

Commonwealth of Australia (2005) 'Risk Analysis Framework developed for genetically modified organisms (GMOs).' (Office of the Gene Technology Regulator, Canberra).

Coops NC, Catling PC (1997) Utilising airborne multispectral videography to predict habitat complexity in eucalypt forest for wildlife management. *Wildlife Research* **24**, 691-703.

Crawford C (2003) Qualitative risk assessment of the effects of shellfish farming on the environment in Tasmania, Australia. *Ocean and Coastal Management* **46**, 47-58.

Cree L (2003) Risk assessment: A tool for decision-making. Sudden Oak Death Online Symposium. http://www.apsnet.org/online/sod/signup.asp

Daily GC (1997) Introduction: what are ecosystem services. In 'Nature's services: societal dependence on natural ecosystems.' (Ed GC Daily) (Island Press: Washington DC).

DeKeyser ES, Kirkby DR, Ell MJ (2003) An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. *Ecological Indicators* **3**, 119-133.

Department of Environment and Heritage Website – Threatened Ecological Communities. http://www.deh.gov.au/biodiversity/threatened/communities/index.html, accessed 06/09/05.

Department of Environment, Sport and Training (1994) 'State of the environment reporting: framework for Australia.' (Department of Environment, Sport and Territories, Canberra).

Department of Sustainability and Environment (2004). 'Draft Strategic Plan for Management of *Phytophthora cinnamomi'* (Department of Sustainability and Environment, Victorian Government, Melbourne, Australia).

DEC (2001) Directive 2001/18/EC on the deliberate release into the environment of GMOs. (European Union).

DETR (1999) Guidance on principles of risk assessment and monitoring for the release of GMOs (DETR, United Kingdom).

Drenth A, Wagels G, Smith BN, Maclean DJ, Irwin J (1998) Detection and identification of Phytophthora. In: 'Patch deaths in tropical Queensland rainforests: association and impact of *Phytophthora cinnamomi* and other soil borne pathogens' (Ed PA Gadek) pp77-84 (Cooperative Research Centre for Tropical Rainforest Ecology and Management, Technical Report, Cairns).

Duncan RP, Bomford M, Forsyth DM, Conibear L (2001) High predictability in introduction outcomes and the geographical range size of introduced Australian birds: a role for climate. *Journal of Animal Ecology* **70**, 621-632.

Ehrlich PR, Ehrlich AH (1981) Extinction: The causes and consequences of the disappearance of species. (Ballantine Books, New York).

Elliston L, Matthews L, Yainshet A (2004a) Managing disease incursions: an economic perspective. *Australian Commodities* **11**(1), 172-179.

Elliston L, Yainshet A, Hinde R (2004b) Karnal Bunt: The regional economic effect of a potential incursion. (ABARE *e*report 40.4 prepared for Plant Health Australia, Canberra).

Environment Australia (2001) Threat Abatement Plan for Dieback caused by the root-rot fungus (*Phytophthora cinnamomi*). Environment Australia, Canberra. http://www.deh.gov.au/biodiversity/threatened/publications/tap/phytophthora/

Environment Australia website, htpp:/www.ea.gov.au, accessed 12/07/05.

Fiskel JR, Covello VT (1985) The suitability and applicability of risk assessment methods for environmental application of biotechnology. In 'Biotechnology risk assessment: Issues and methods for environmental introductions.' (Eds JR Fiskel, VT Covello) pp355-367 (Pergamon Press, New York).

Francis RICC (1992) Use of risk analysis to assess fishery management strategies: a case study using Orange Roughy (*Hoplostethus atlanticus)* on the Chatham rise, New Zealand. *Canadian Journal of Fisheries and Aquatic Science* **49**, 922-930.

Gadek PA, Worboys S, Eds. (2003) Rainforest Dieback Mapping and Assessment: Phytophthora species diversity and impacts of dieback on rainforest canopies. (Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns).

Garavanta CAM, Wooller RD, Richardson KC (2000) Movement patterns of honey possums, *Tarsipes rostratus*, in the Fitzgerald River National Park, Western Australia. *Wildlife Research* **27**, 179-183.

Gibson M, Milne R, Cahill D, Wilson B, Baker D (2002) Preliminary review of the actual and potential distribution of *Phytophthora cinnamomi* dieback in parks and reserves across Victoria, pp1-70, Research Report, University of Ballarat, Australia.

Groves RH, Panetta FD, Virtue JG (2001) Weed risk assessment. (CSIRO Publishing, Collingwood, Australia).

Groves E, Hardy GEStJ, McComb J (2003) Native Garden Plants resistant to Dieback (*Phytophthora cinnamomi*). Murdoch University. http://www.cpsm.murdoch.edu.au/downloads/resources/B_resistantspecies.pdf

Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. *Ecological Modelling* **135**, 147-186.

Harris HJ, Wenger RB, Harris VA, DeVault DS (1994) A method for assessing environmental risk: a case study of Green Bay, Lake Michigan, USA. *Environmental Management* **18**, 295-306.

Hart BT, Lake PS, Webb JA, Grace MR (2003) Ecological risk to aquatic systems from salinity increases. *Australian Journal of Botany* **51**, 689-702.

Hayes KR (2002a) Identifying hazards in complex ecological systems. Part 1: fault-tree analysis for biological invasions. *Biological Invasions* **4**, 235-249.

Hayes KR (2002b) Identifying hazards in complex ecological systems. Part 1: infection modes and effects analysis for biological invasions. *Biological Invasions* **4**, 251-261.

Hayes KR, Gregg PC, Gupta VV, Jessop R, Lonsdale WM, Sindel B, Stanley J, Williams CK (2004) Identifying hazards in complex ecological systems. Part 3: Hierarchical Holographic Model for herbicide tolerant oilseed rape. *Environmental Biosafety Research* **3**(2), 109-128.

Hill J, Cahill D, Wilson BA (2005) High-resolution quantification of the effect of *Phytophthora cinnamomi* on heathland at Anglesea, Victoria. *in press*

IRC (2002) Western Rock Lobster ecological risk assessment. IRC Environment, Project JOO-207. Report to the Western Australian Department of Fisheries, Perth, Western Australia.

Jimmerson TM (1999) A conservation strategy for Port-Orford-Cedar. Unpublished paper. (Siskiyou National Forest, Medford, Oregon).

Kumamoto H, Henley EJ (1996) Probalistic Risk Assessment and Management for Engineers and Scientists. 2nd Edition. (IEEE Press, New York).

Lacy RC (1993) Vortex: a computer simulation model for population viability assessment. *Wildlife Research* **20**, 45–65.

Laidlaw WS (1997) The effects of *Phytophthora cinnamomi* on heathland flora and fauna of the eastern Otway Ranges. (PhD Thesis, Deakin University, Victoria).

Lauver CL, Busby WH, Whislter JL (2002) Testing a GIS model for habitat suitability for a declining grassland bird. *Environmental Management* **30**, 88-97.

Lee TC, Wicks TJ (1977) *Phytophthora cinnamomi* in native vegetation in South Australia. *Australasian Plant Pathology Newsletter* **6**, 22-23.

Leversha J, Gibson M, Westbroke M, Callister K (2001) Rapid assessment of vegetative condition: development and trial of techniques. Report prepared by the Centre for Environmental Management, University of Ballarat, for Parks Victoria.

Lewis JL (2002) Mapping Risk from Forests Insects and Diseases. (USA Department of Agriculture and Forests Service).

Lihou (2002) HAZOP. Version 4.0: An integrated system for the recording, reporting and analysis of hazard and operability studies and other safety reviews. (Lihou Technical and Software Services, Birmingham, England).

Lindenmayer DB, Lacy RC, Thomas VC, Clark TW (1993) Prediction of the impacts of changes in population size and environmental variability on Leadbeater's Possum, *Gymnobelideus leadbeateri* (McCoy) using population viability analysis: An application of the computer program Vortex. *Wildlife Research* **20**, 67–86.

Lindenmayer DB, Possingham HP (1996) Modelling the inter-relationships between habitat patchiness, dispersal capability and metapopulation persistence of the endangered species, Leadbeater's possum, in south-eastern Australia. *Landscape Ecology* **11**, 79–105.

Lindenmayer DB, Cunningham RB, McCarthy MA (1999) The conservation of arboreal marsupials in the montane ash forests of the central highlands of Victoria, south-eastern Australia. VIII. Landscape analysis of the occurrence of arboreal marsupials. *Biological Conservation* **89**, 83-92.

Lopez RD, Fennessy MS (2002) Testing the floristic quality assessment index as an indicator of wetland condition. *Ecological Applications* **12**, 487-497.

Luo Y, TeBeest DO, Teng PS, Fabellar (1995) Simulation studies on risk analysis of rice blast epidemics associated with global climate in several Asian countries. *Journal of Biogeography* **22**, 673-678.

MAF Biosecurity Authority (2002). Ministry of Agriculture and Forestry, New Zealand http://www.maf.govt.nz/imports/forests/standards/douglas-fir-sudden-oak-death-proposal.pdf, accessed 02/04/05.

Maxwell S, Burbidge AA, Morris K (Eds) (1996) The 1996 Action Plan for Australian Marsupials and Monotremes. (Wildlife Australia, Canberra).

Morton SR (1990) The impact of European settlement on the vertebrate animals of arid Australia: a conceptual model. *Proceedings of the Ecological Society of Australia* **16**, 201–213.

Morton S, Bourne G, Christophani P, Cullen P, Possingham H, Young M (2002) Sustaining our natural resources and biodiversity. Independent Report to Prime Minister's Science, Engineering and Innovation Council, CSIRO and Environment Australia, Canberra.

Niewand G, Smith I, Geary G (1995) Phytophthora cinnamomi control in parks. (National Parks Service Guidelines and Procedures Manual, Department of Conservation and Natural Resources, East Melbourne).

Norberg J (1999) Linking nature's services to ecosystems: some general ecological concepts. *Ecological Economics* **29**, 183-202.

Noss RF (1990) Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology* **4**(4), 355- 365.

Noss RF (1991) From endangered species to biodiversity. In: 'Balancing on the brink of extinction: the Endangered Species Act and lessons for the future.' (Ed KA Kohm) (Island Press, Washington DC).

OGTR (2005) 'Risk analysis framework'. (Office of the Gene Technology Regulator, Canberra).

Peters D (1995) An Operational Guide to Minimise the Spread of *Phytophthora cinnamomi* in the Brisbane Ranges and Steiglitz Areas. (Department of Conservation and Natural Resources, Melbourne).

Peterson G, Allen CR, Holling CS (1998) Ecological resilience, biodiversity and scale. *Ecosystems* **1**, 6-18.

Pheloung PC (1996) CLIMATE: a system to predict the distribution of an organism based on climate preferences. (Agriculture Western Australia, Perth).

Phytophthora Technical Group (2003) Phytophthora Management Guidelines. Department for Environment and Heritage, South Australia. http://www.environment.sa.gov.au/biodiversity/pdfs/pc_management_guidelines.pdf

Podger FD, Mummery DC, Palzer CR, Brown MJ (1990) Bioclimatic analysis of the distribution of damage to native plants in Tasmania by *Phytophthora cinnamomi*. *Australian Journal of Ecology* **15**, 281-289.

Podger FD (1999) A National Overview of *Phytophthora cinnamomi* in Australia. Supplementary information to accompany the draft National Threat Abatement Plan. (Environment Australia, Canberra).

Possingham H, Ryan S, Baxter J, Morton S (2002) Setting Biodiversity Priorities (Sustaining our Natural Systems and Biodiversity: Prime Ministers Science and Engineering Innovation Council).

Prime Minister's Science Council (1992) Scientific Aspects of Major Environmental Issues: Biodiversity. (Australian Government Publishing Service, Canberra).

Punt AE, Hillborn R (1997) Fisheries stock assessment and decision analysis: The Bayesioan approach. (CSIRO Division of Marine Research, Hobart, Australia).

RAPRA website - Risk analysis for *Phytophthora ramorum*, http://rapra.csl.gov.uk, accessed 2/9/05.

Royal Botanic Gardens and Domain Trust (2003) 2002 –2003 Annual Report of the Plant Sciences Branch, Royal Botanic Gardens and Domain Trust, NSW. http://www.rbgsyd.nsw.gov.au/data/page/910/PSReport_02-03.pdf

Rushton SP, Ormerod SJ, Kerby G (2004) New paradigms for modelling species distributions. *Journal of Applied Ecology* **41**, 193-200.

Saunders D, Margules C, Hill B (1998) Environmental indicators for national State of the Environment reporting in Biodiversity, State of the Environment, Environmental Indicator Reports. (Department of the Environment, Canberra).

Schahinger R, Rudman T, Wardlaw TJ (2003) Conservation of Tasmanian Plant Species and Communities threatened by *Phytophthora cinnamomi*. *Strategic Regional Plan for Tasmania*. Technical Report 03/03, Nature Conservation Branch, Department of Primary Industries, Water and Environment, Hobart.

Scheffer M, Carpenter S, Foley JA, Folke C, Walker B (2001) Catastrophic shifts in ecosystems. *Nature* **413**, 591-596.

SCRIPT (2004) *Phytophthora cinnamomi*: Mapping the threats and building the capacity to manage them (South Coast Region Initiate Planning Team, Albany, Western Australia).

Shaw T, Britton K (2003) Sudden Oak Death Problem, Unites States of America. (National Strategic Plan Draft, USDA FS-R&D; USDA FS-FHP).

Shearer BL, Crane CE, Cochrane A (2004) Quantification of the susceptibility of the native flora of the South-West Botanical Province, Western Australia to *Phytophthora cinnamomi*. *Australian Journal of Botany* **52**, 435-443.

Short J, Smith AP (1994) Mammal decline and recovery in Australia. *Journal of Mammalogy* **75**, 288–297.

Simpson EH (1949) Measurement of diversity. *Nature* **163**, 688.

Smith AP, Quin DG (1996) Patterns and causes of extinction and decline in Australian Conilurine Rodents. *Biological. Conservation* **77**, 243-267.

State of the Environment Advisory Council (1996) State of the Environment of Australia Report. Independent Report Presented to the Commonwealth Minister for Environment. (CSIRO Publishing, Melbourne).

Stone C, Coops N, Culvenor D (2000) Conceptual development of a eucalypt canopy condition index using high resolution spatial and spectral remote sensing imagery *Journal of Sustainable Forestry* **11**, 23-45.

Strelein GJ, Sage LW, Blankendaal PA (2005) Rates of disease extension of *Phytophthora cinnamomi* in the Jarrah forest (*Eucalyptus marginata*) bioregion of south-western Australia.

Suter GW II (1993a) Ecological risk assessment. (Lewis Publishers, Chelsea, Michigan).

Suter GW II (1993b) A critique of ecosystem health concepts and indexes. *Environmental Toxicology and Chemistry* **12**, 1533-1539.

Sutherst RW, Maywald GF (1985) A computerised system for matching climates in ecology. *Agriculture Ecosystems and Environment* **13**, 281-299.

Sutherst RW, Yonow T, Chakraborty S, O'Donnell C, White N (1996) A generic approach to defining impacts of climate change on pests, weeds and diseases in Australasia. In: *Greenhouse, coping with climate change* (Eds WJ Bouma, GI Pearman, MR Manning) pp281-307 (CSIRO, Australia).

Sydney Harbour Trust Fund (2004) Phytophthora and Vegetation Dieback in Sydney Harbour's Bushland. http://www.harbourtrust.gov.au/downloads/acrobat/otherpubs/phytophthorabrochure.pdf

Teng PS, Heong KL, Kropff MJ, Nutter FW, Sutherst RW (1996) Linked pest-crop models under global change. In: *Global change and terrestrial ecosystems* (Eds B Walker, S Will), pp291-316 (Cambridge University Press, Cambridge).

USDA Forest Service website - Sudden Oak Death Research, *Phytophthora ramorum*, www.fs.fed.us/psw/programs/sod, accessed 12/4/05

Vandemark, G (2003) Real Time PCR Assays for Examining Resistance to *Aphanomyces euteiches* and *Phytophthora medicaginis* in Legumes and for Studying Microbial Population Dynamics in Mixed Plant Infections. United States Department of Agriculture. www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=156018

Velzeboer R, Stubbs W, West A, Bond A, Urban R (2005) Threatened plant species in South Australia that may be threatened by Phytophthora – a risk assessment (DRAFT). An unpublished report from the Department for Environment and Heritage, (Government of South Australia).

Walker B, Carpenter SR, Anderies JM, Anel N, Cumming G, Janssen M, Lebel L, Norberg J, Peterson GD, Pritchard R (2002) Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology* **6**, 14.

Wenger RB, Harris HJ, DeVault DS (2000) An assessment of ecosystem risks in the St. Croix National Scenic Riverway. *Environmental Management* **25**, 599-611.

Weste G (1981) Changes in the vegetation of sclerophyll shrubby woodland associated with invasion by *Phytophthora cinnamomi*. *Australian Journal of Botany* **29**, 261-276.

Weste G (1986) Vegetation changes associated with invasion by *Phytophthora cinnamomi* of defined plots in the Brisbane Ranges, Victoria, 1975-1986. *Australian Journal of Botany* **34**, 633-648.

Weste G, Ashton DH (1994) Regeneration and survival of indigenous dry sclerophyll species in the Brisbane Ranges, Victoria, after a *Phytophthora cinnamomi* epidemic. *Australian Journal of Botany* **42**, 239-253.

Weste G, Brown K, Kennedy J, Walshe T (2002) *Phytophthora cinnamomi* infestation – a 24 year study of vegetation change in forests and woodlands of the Grampians, Western Victoria. *Australian Journal of Botany* **50**, 247-274.

Westman WE (1986). Resilience: concepts and measures. In: Resilience in Mediterranean-Type Ecosystems. (Eds. B Dell, AJM Hopkins, BB Lamont) p5 (Dr W Junk Publishers).

Wills RT (1993) The ecological impact of *Phytophthora cinnamomi* in the Stirling Range National Park, Western Australia. *Australian Journal of Ecology* **18,** 145-159.

Wilson BA, Laidlaw WS (2001) Impact of *Phytophthora cinnamomi* on mammals in southern Australia. Proceedings of 2nd International IUFRO Meeting. Albany, Western Australia.

Wilson BA, Newell G, Laidlaw WS, Friend G (1994) Impact of plant diseases on faunal communities. *Journal of the Royal Society of Western Australia* **77**, 139-144.

Wilson BA, Lewis A, Aberton J (1997) Conservation of national estate communities threatened by cinnamon fungus at Anglesea, Victoria. pp 93 Report for the Department of Natural Resources and Environment.

Wilson BA, Aberton J, Cahill D (2000) The relationship between site factors and distribution of *Phytophthora cinnamomi* in the Eastern Otway Ranges, Victoria. *Australian Journal of Botany* **48**, 247-260.

Wilson BA, Aberton J, Lewis A (2003) A spatial model for predicting the presence of cinnamon fungus (*Phytophthora cinnamomi*) in sclerophyll vegetation communities in south-eastern Australia. *Austral Ecology* **28**, 108-115.

Wooller RD, Richardson KC, Bradley GO (1999) Dietary constraints upon reproduction in an obligate pollen-and nectar-feeding marsupial, the honey possum (*Tarsipes rostratus*). *Journal of Zoology* **248**, 279-287.

Wooller RD, Richardson KC, Garavanta CAM, Saffer VM, Bryant KA (2000) Opportunistic breeding in the polyandrous honey possum, *Tarsipes rostratus*. *Australian Journal of Zoology* **48**, 669-680.

Worboys S, Gadek P, Abell S, Jensen R (2003) Impact of dieback on rainforest canopies. In: 'Rainforest Dieback Mapping and Assessment: Phytophthora species diversity and impacts of dieback on rainforest canopies'. (Eds. PA Gadek and S Worboys) pp23-68 (Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns).

World Conservation Monitoring Center (1992) Global Diversity: Status of the Earth's Living Resources. (Ed B Groombridge) (Chapman & Hall, London).

8 GLOSSARY

accredited

Official recognition by an authorised body that a person or organisation is capable of undertaking a task, or producing a product according to specific criteria and standards.

actuarial risk

Based on data, i.e. is observable and assessable, therefore quantitative.

baiting

A method by which a plant pathogen is isolated for identification from an infected substrate, by encouraging the pathogen to infect fresh plant material (the bait) from which relatively pure culture can be attained. It is a particularly useful technique for zoosporic pathogens such as *Phytophthora.*

best practice

A superior method or innovative practice that contributes to the improved performance of an organisation, usually recognised as "best" by other peer organisations (general Web definition).

biodiversity

The variability among living organisms from all sources (including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part) and includes: (a) diversity within species and between species; and (b) diversity of ecosystems (EPBC Act, 1999 http://scaleplus.law.gov.au/html/pasteact /3/3295/2 /PA010810.htm). A contraction of, and synonymous with, the term 'biological diversity'.

biodiversity hotspots

Areas of the world that contain highest biodiversity.

consequence

The outcome of an event expressed qualitatively or quantitatively, being loss or injury, disadvantage or gain (AS/NZS 4360: 1999).

conservation significance/value

Sites possessing uncommon, rare or endangered aspects of Australia's natural or cultural history.

cost-benefit analysis

The appraisal of an investment project including all social and financial costs and benefits accruing to the project (http://bch-cbd.naturalsciences.be/belgium/glossary /glos_c.htm).

critically endangered

Species that have been recognised as critically threatened. The categories of species listed as threatened under the EPBC Act are as follows: a) extinct; b) extinct in the wild; c) critically endangered; d) endangered; e)vulnerable and; f) conservation dependent (EPBC Act, 1999 http://scaleplus.law.gov.au/html/pasteact/3/3295/2/PA010810.htm).

dieback

A symptom of plant disease in which there is a progressive death of shoots, leaves and roots beginning at the tips (American Phytopathological Society website glossary http://www.apsnet.org/Education/IllustratedGlossary/). Commonly used in Australia to describe the symptoms of individual plants, or a general decline in the health and numbers of plants in the landscape as a result of disease caused by pathogens of the genus *Phytophthora*.

Dieback Working Group

The Dieback Working Group is a West Australian government, industry and community focused group funded by the National Heritage Trust. The Dieback Working Group was formed in 1996 as an initiative to increase the level of communication between State government departments, local government authorities and community groups. The DWG has been mapping *P. cinnamomi* in reserves in the metropolitan area and is beginning to do more now on the south coast of Western Australia.

ecological processes

Processes that have an essential part in maintaining ecosystems; four fundamental ecological processes are the cycling of water, the cycling of nutrients, the flow of energy and biodiversity (State of the Environment Report, 2001 Biodiversity http://www.deh.gov.au/soe/2001/biodiversity/pubs/biodiversity.pdf).

ecosystem

A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit (EPBC Act 1999 http://scaleplus.law.gov.au/html/pasteact/3/3295/2/PA010810.htm).

ecosystem integrity

The degree to which the fundamental ecological processes are maintained (State of the Environment Report, 2001 Biodiversity http://www.deh.gov.au/soe/2001/biodiversity/pubs/biodiversity.pdf).

ecosystem function

The functioning of the fundamental ecological processes in an ecosystem.

ecosystem resilience

Can be defined in two ways. The first is a measure of the magnitude of disturbance that can be absorbed before the (eco)system changes its structure by changing the variables and processes that control behaviour. The second, a more traditional meaning, is as a measure of resistance to disturbance and the speed of return to the equilibrium state of an ecosystem. (http://bch-cbd.naturalsciences.be/belgium/glossary/glos_e.htm).

ecosystem services

This term describes the processes and conditions by which natural ecosystems sustain and fulfil human life. Services such as nutrient cycling, soil formation, clean air, water cycling and purification, biomass production, crop pollination and provision of food (www.vcmc.vic.gov.au/Web/ Docs/Executive%20Summary%20CCR.doc).

endangered species

Species that have been recognised as threatened. A category of threatened species under the EPBC Act: a) extinct; b) extinct in the wild; c) critically endangered; d) endangered; e)vulnerable and; f) conservation dependent (EPBC Act, 1999

endemic

Native to a particular area and nowhere else.

event tree

A similar procedure to a fault tree with a bottom up approach with the primary event specified and the consequences of the primary event traced forward.

ex-situ conservation

The conservation of components of biological diversity outside their natural habitats (EEA - Convention on Biological Diversity (art.2)).

fault tree

The fault tree is a top-down approach employed to identify hazards and design strategies to mitigate them by identifying a failure or fault and identifies all the causative events leading to the failure. A procedure is employed to link all the processes and events that lead to outcomes or failures.

geographic information systems (GIS)

A package of computer programs specifically designed to collect, store, retrieve, manipulate, analyse and display mapped data (adapted from State of the Environment Report, 2001 http://www.deh.gov.au/soe/2001/biodiversity/pubs/biodiversity.pdf).

habitat

The biophysical medium or media: (a) occupied (continuously, periodically or occasionally) by an organism or group of organisms; or (b) once occupied (continuously, periodically or occasionally) by an organism, or group of organisms, and into which organisms of that kind have the potential to be reintroduced (EPBC Act, 1999 http://scaleplus.law.gov.au/html/ pasteact/3/3295/2/PA010810.htm).

hazard

A source of potential harm or a situation with a potential to cause loss (AS/NZS 14001: 1996).

infected

When an organism has entered, invaded or penetrated and established a parasitic relationship with a host plant (American Phytopathological Society website glossary http://www.apsnet. org/Education/IllustratedGlossary/).

infested

Used of fungi in soil or other substrate in the sense of 'contaminated' (Hawksworth *et al.* 1995).

key threatening process

A process that threatens or has the potential to threaten the survival, abundance or evolutionary development of a native species or ecological community (http://www.deh. gov.au/biodiversity/threatened/ktp/).

likelihood

A qualitative or quantitative description of probability or frequency (AS/NZS 4360: 1999).

listed threatened species or communities

Species that have been recognised as threatened through a legislative process by Commonwealth or State/Territory Governments, in which species are divided into categories according to the level of the threat. The categories of threat vary slightly between States. The categories of species listed as threatened under the EPBC Act are as follows: a) extinct; b) extinct in the wild; c) critically endangered; d) endangered; e) vulnerable and; f) conservation dependent (EPBC Act, 1999 http://scaleplus.law.gov.au/html/pasteact/3/3295/2/PA010810.htm). Listing helps to select and rank the species most in need of practical conservation, which should set in train the processes needed to facilitate de-listing, as the ultimate goal of practical conservation (www.deh.gov.au/biodiversity/threatened/action/butterfly/ status.html).

listed threatened communities

Communities that have been recognised as threatened through a legislative process by Commonwealth or State/Territory Governments, in which communities are divided into categories according to the level of the threat. The categories of threat vary slightly between States. The categories of species listed as threatened under the EPBC Act are as follows: a) critically endangered; d) endangered; e) vulnerable (EPBC Act, 1999 http://scaleplus.law. gov.au/html/pasteact/3/3295/2/PA010810.htm).

long term monitoring sites

Mapped, surveyed areas that are permanently pegged to enable comparisons of the effect of disease or spread over a long period of time (decades).

NATA accreditation

The Association of testing authorities Australia (NATA) is a national body for the accreditation of laboratories and similar testing facilities. A NATA accredited laboratory conforms to Australian standards and achieves the highest level of competence.

NIASA

Nursery Industry Accreditation Scheme (Australia) is a voluntary national scheme for production nurseries and growing media businesses, which operate in accordance with a set of national 'best practice' guidelines that includes practices and procedures for the hygienic production of plants. (NGIA website, accessed 03/10/04)

notional risk

On models-uncertainty, probabilistic

on-ground management

The delivery and execution of processes and procedures for the management of *P. cinnamomi* in natural ecosystems.

park/reserve management plan

For protected areas (e.g. Parks and Reserves), area specific documents which detail actions that need to be carried in order to manage the natural and cultural values of the area. Most *P. cinnamomi* management plans for a site are tactical

phosphite

An aqueous solution of mono-potassium phosphite and di-potassium phosphite. (CALM's Best Practice Guidelines, 2004). Also called phosphonate.

Project Reference Group

A representative advisory committee for the CPSM (DEH)project comprising members drawn from of a range of agencies and institutions across the nation currently responding to the threat. It will provide input into the CPSM project outcomes.

qualitative risk assessment

Analyses utilising relative descriptions of likelihood and consequences and are generally based on best estimates and expert opinions.

quantitative modelling techniques

Modelling that employs numerical values and produce predictions that can be scientifically tested.

rare species

Fauna and flora species that are small or scarce in number and distribution.

recovery plans

The Australian Government Minister for the Environment and Heritage may make or adopt and implement recovery plans for threatened fauna, threatened flora (other than conservation dependent species) and threatened ecological communities listed under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC

Act). Recovery plans set out the research and management actions necessary to stop the decline of, and support the recovery of, listed threatened species or threatened ecological communities. The aim of a recovery plan is to maximise the long term survival in the wild of a threatened species or ecological community (http://www.deh.gov.au /biodiversity/threatened/recovery/index.html).

resilience

The capacity of a system damaged by disturbance to return to its prior state if the disturbance is removed (Westman, 1986).

resistance

The power of an organism to overcome, completely or in some degree, the effect of a pathogen or other damaging factor (Hawksworth DL, Kirk PM, Sutton BC and Pegler DN [1995] Ainsworth and Bisby's Dictionary of the Fungi. 8th Edition. CAB International, Wallingford, UK).

risk

The chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood (AS/NZS 4360: 1999).

risk analysis

A systematic use of available information to determine how often specified events may occur and the magnitude of their consequences (AS/NZS 4360: 1999).

risk assessment

The overall process of risk analysis and risk evaluation (AS/NZS 4360: 1999) involving probabilities, frequencies, magnitude, and consequences.

risk evaluation

The process used to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels or other criteria (AS/NZS 14001: 1996).

risk management

The culture, processes and structures that are directed towards the effective management of potential opportunities and adverse effects (AS/NZS 4360: 1999).

risk management process

The systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risk (AS/NZS 14001: 1996).

risk mapping

The presentation of the results of risk assessment on a map, showing the levels of expected losses which can be anticipated in specific areas, during a particular time period, as a result of particular disaster hazards (www.cwserp.org/training/CWSEMT/KCmodulea.php).

spatial model

The application of modelling techniques for analysing, patterns of distribution of organisms and communities.

stakeholders

Any individual or groups that are affected by regulations for and approaches to the management of *P. cinnamomi* in the environment.

standard

A published document which sets out specifications and procedures designed to ensure that a material, product, method or service is fit for its purpose and consistently performs the way it was intended to (Standards Australia http://www.standards.org.au/DEVELOPMENT/ OVERVIEW/DEFAULT.HTM).

strategic risk assessment

The use of risk assessment methods to determine corporate activities such as allocating resources or making informed decisions.

stressors

Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Stressors are chemical, physical or biological entities, natural and unnatural events or activities that adversely affect ecosystem processes, habitats and species (science.nature.nps.gov/im/monitor/glossary.htm).

structured induction

Systematic, logical procedures are developed to identify potential hazards based on identifying all components, sub-components, combinations and operating modes of the systems.

susceptible

Lacking the inherent ability to resist disease or attack by *P. cinnamomi.* Species which have high mortality in the field.

tactical risk assessment

The objective methods for quantitative risk assessment developed for assessing adverse effects of factors such as chemicals, or planned industrial developments.

threat

An indication that serious or irreversible environmental damage may occur (CALM’s Best Practice Guidelines, 2004).

threatened species

A native species may be declared a threatened species when it is considered conservation dependent or vulnerable. (Section 178: http://www.deh.gov.au/biodiversity). Section 179 (6): the species is the focus of a specific conservation program, the cessation of which would result in the species becoming vulnerable, endangered or critically endangered within a period of 5 years.

uninfested

Areas that are deemed to be free of *P. cinnamomi* by a qualified or suitably experienced person through an assessment of vegetation for indicators of disease (CALM's Best Practice Guidelines, 2004).

unstructured deduction

When checklists are developed to identify potential hazards based on previous experiences.

vector

Any agent that carries *P. cinnamomi* from one place to another.

vulnerable

Susceptible to physical injury (CALM's Best Practice, 2004). Also used to formally describe a category of threat to species and ecological communities in Australia (see 'listed threatened species' and 'listed threatened communities').

vulnerable zone

Areas where the there is a coincidence of environmental conditions conducive to the establishment of *P. cinnamomi* and susceptible native vegetation, so that introduction of the pathogen is likely to result in negative impact due to disease.